Semi-Autonomous UAV based Weather and Air Pollution Monitoring System

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Abstract: With air pollution increasing at an alarming rate, it has drastic health and economic effects on the urban centers across the world. Optimized monitoring and controlling methods are required for obtaining the good performance of the sensors. It is important to mitigate disasters due to pollution; the proposed work has contributed to monitoring the atmosphere's pollutant concentration with greater precision. To use a semi-autonomous unmanned aerial vehicle to remotely measure the air pollution at a suitable height and wirelessly transmit the data logged into the ground station. The ground station directly updates the server's real-time values to be monitored using the simulation software's graphical user interface. The CO₂, CO, Temperature, and Humidity values are collected, and proper algorithms are used to prevent data duplication and practical data extraction from the database. The ultra-high frequency (UHF) band is used for wireless transmission. It helps the Quadcopter mounted sensor module to monitor a large area while simultaneously updating the server's values. This type of pollution monitoring can help plants such as refineries, integrated industries, thermal power plants, etc., to regulate pollutants' emissions to the atmosphere. The semi-autonomous UAV-based data collection and testing are carried in the field of polluted areas.

Keywords: Wireless Communication, Pollution, Weather Monitoring, Gas Sensors, Quadcopter, Real-Time, GUI

1. INTRODUCTION

With the government's Smart City Mission, pollution monitoring and weather monitoring become crucial. With the funds allocated for the 100 cities to be turned into Smart Cities and 500 others to be developed, it is a costly affair to meteorological setup stations in every place [1][2][3]. More and more industries are also being set up every day, contributing to a significant amount of Green House Gases and toxic pollutants in the atmosphere [4]. With many industries, there is always a risk of poisonous gases escaping into the atmosphere.

Weather prediction and detection of natural calamities are also becoming very important in our day-to-day lives. A smart city always requires high surveillance and fast action monitoring in any catastrophe [5][6]. Issues such as power consumption and reliability of data transmission arise during data collection into the sink. A large amount of data collection needs to be addressed as essential data only needs to reach the control server for determining the response. Drones can supplement the
requirement for sink-in platforms to collect data from various sensor nodes [7]. The toggle button type switches are found in the transmitters; the control command can be transmitted as per the user's requirement. The system would deploy wireless sensor networks that would acquire data from different parts of the city or places. This system will include a drone for surveillance and monitoring purposes [8] [9]. The system is also connected to the internet, and the users can get details about the air pollution index and weather forecasts in real-time. Besides, algorithms would be implemented for preventing data duplication and enabling data fusion. Decentralization of data collection points to ensure accuracy and faster data upload rate. Finally, a GUI would be developed to monitor the entire job, from collecting information to the particular process generation.

Section 1 has the factors that led to the prototype's development and how it could meet the proposed concept's current demands. Sections 2 and subsection depict the sequence in which the data is acquired until it is displayed in the server and analysed; the components used in the Quadcopter and the sensor module are described briefly. In section 3, flowcharts and systemic models are represented, and tables with details about measurands are noted. In section 4, the results and observations from SD Card and Static and Dynamic Sensing are illustrated. Finally, sections 5 and 6 in which the proposed work is stated and references are provided.

2. MODEL OF THE SEMI-AUTONOMOUS UNMANNED AERIAL VEHICLE

The semi-autonomous unmanned aerial vehicle's design to monitor the air pollution and the weather was undertaken in the current work. The various individual parts of the Quadcopter were studied. The power module was designed for the entire system. Then the flight controller was programmed, and the Quadcopter was calibrated for the 2.4 GHz transmitter until the Quadcopter was stable in the air.

Low cost embedded processor was used for data logging from various Environment and weather sensors. The CO₂, CO, temperature, and humidity sensors were interfaced, and the codes were written to capture the values. The sensors were finally calibrated based on the datasheets. The proposed module was yet mounted on the UAV to undertake data acquisition in dynamic conditions with a specific offset.

The communication module was finally designed with a UHF band transmitter and receiver, and they were interfaced with the Arduino controller. The transmitter is kept on the UAV platform, while the receiver is mounted in the ground station to receive the data wirelessly. Using Node.js and JSON, the information is uploaded into the server where after processing through the code written, the GUI finally displays the maximum, minimum, and average values. Fig.1 shows the experimental setup of the UAV, controller, and data monitoring station.

Fig 1. Experimental setup for weather monitoring station.
2.1. Basic principles of quadcopter operation
The atmosphere acts as a fluid that contains the drag force. This force resists the upward, sideways, and other motion of the Quadcopter. Thus, the motors have to provide the RPM accordingly to overcome the drag force and fly in the transmitter's required direction. Thrust is the force generated by propellers and motors' motion, which exceeds the drag force and carries the Quadcopter upwards or in any other order.

Similarly, the Quadcopter weight applies a downward force due to the influence of attraction due to gravity on its weight. The Quadcopter needs a push for vertical lift-off from the ground. The air provides the resistance to lift-off, and thus, enough thrust needs to be produced by the propellers' rotation to lift the Quadcopter. The rotation creates the differences in pressure above and below the propellers, the quadcopter uplifts against the weight. This difference in air pressure is known as the Coanda effect.

The Bernoulli equation is the guiding factor behind the flight of Quadcopter. If the Quadcopter has to move upwards, then pressure downwards must be greater than pressure upwards such that Quadcopter can at least hover. The Quadcopter was tested, and most of the time, the Quadcopter drifted off owing to the imbalance of forces. It must ensure the mode of the Quadcopter in the flight controller and accordingly place different propellers. The wrong orientation of propellers will cause problems during lift-off, and there might be chances of damages to the Quadcopter. Also, need to ensure that the total weight of the Quadcopter after mounting all the desired components should not exceed the maximum weight.

2.2. Axis of the quadcopter and calibration sensing module
Quadcopter is used for remote sensing operation [10][11]. It has four arms with propellers mounted on each of them. Each is accompanied by a brushless DC motor with 930 torque and 10000 rpm speed. These can move in a clockwise and counter-clockwise direction and play a vital role in the Quadcopter flight. The Quadcopter has two modes, '+' mode and '*' mode. One of the configurations is chosen. It must be ensured that the adjacent propellers should be moving in the opposite direction, i.e., one should move in a clockwise direction, and the other should move in the counter-clockwise direction. The accelerometer calibration is done before the flight take-off, and it helps the Quadcopter understand the altitude of the location. It uses a 13.2 V lithium battery for power supply and can sustain in the air with that power for 7 to 10 minutes. Other components include electronic speed controllers, flight controllers, and buck converter were mounted on the Quadcopter. Fig.2 shows the movement of the Quadcopter on a different axis and also shows the flight mode. The entire weight of the Quadcopter is around 700 to 800 grams [12].

![Fig.2: Quadcopter with a different axis for movement](image)

The carbon monoxide sensor (MQ-7) is used to find the carbon monoxide concentration in the atmosphere. Usually, it is 0.01% here the PPM unit is considered. Hence the value should be near 100 ppm, which is equivalent to 0.01% value of CO in air. This sensor has an extensive detection range, quick response, reasonable sensitivity, easy circuit, and better stability [13].
Calibration of MQ-135 Sensor uses the following formula:

\[ R_s = \frac{(50 - (10 \times V_o))}{V_c} \]  \hspace{1cm} (1)

\[ \text{Ratio} = (0.3611) \times \frac{R_s}{R_o} \]  \hspace{1cm} (2)

\[ \text{Value in PPM} = \left(146.15 \times (2.668 - \text{Ratio}) + 10\right) - 300 \]  \hspace{1cm} (3)

DHT11 sensor is used to measure the temperature and humidity of the atmosphere [14]. It gives the digital output. It is interfaced with the Arduino using the DHT11 library present in GitHub. It uses digital signal processing and sampling techniques to collect the data, thus ensuring reliability and stability. One of the most significant advantages of using this sensor is that it is previously calibrated. It can measure extensive temperature ranges and relative humidity in the atmosphere. It consumes minimum power and, unlike thermistors, doesn't require additional components.

The carbon dioxide sensor (MQ-135) is used for measuring the concentration of carbon dioxide in the atmosphere [15]. The carbon dioxide concentration present in the atmosphere is about 0.03%, while the sensor used here measures the concentration in parts per million. Hence the equivalent amount of carbon dioxide that should be present is around 300. It gives both analog and digital output. The sensor is calibrated and then used to find the concentration of carbon dioxide present in the atmosphere.

\[ \text{Value in PPM} = 3.027 \times e^{0.6598 \times \text{VRL}} + 100 \]  \hspace{1cm} (4)

The transmitter and receiver used here work in the UHF band [16] [17]. The UHF uses a frequency of 315 MHz to transmit and receive data. Unicode is used to encode and decode data for transmission. The values acquired are first converted to character format and then sent to the receiver. The data transfer rate is 3 to 300 bps, and it uses Amplitude Shift Keying to transfer the data into the receiver. They are interfaced into the Arduino using the Virtual Wire library found in GitHub. The Arduino PIN 12 is used as a transmitter, and the Arduino PIN 11 is used as the receiver pin. Finally, the data is transmitted and uploaded in real-time. The detailed specification of the transmitter and receiver is mentioned in Table 1 and Table 2.

| Table 1. Transmitter specifications |
|-------------------------------------|
| **Parameters** | **Values** |
| Total Range of Frequency | 315 /433.92 MHZ. |
| Voltage Provided | 3~12V. |
| Power Throughput | 4~16dBm |
| Waveform | Saw |
| Speed of Data Transfer | 200-3000 bps |

| Table 2. Receiver specifications |
|----------------------------------|
| **Parameters** | **Values** |
| Frequency Range | 315 /433.92 MHZ. |
| Supply Voltage | 5 V. |
| Output Power | 40-60 % |
| Circuit Shape | Saw |
| Data Rate | 300 - 3000 bps |

A superheterodyne receiver is used by the receiver based on ASK for decoding the received data. A phase-locked loop and oscillator crystal circuit are used here.
3. METHODOLOGY

The steps involved in the development of the onboard model shown in Fig.3. Develop architecture to define nodes and their interaction.

Collect readings of various environmental parameters from the region of interest. Collaboration among many nodes collects readings and transmits them to a gateway while minimizing duplicates and invalid values. Use of appropriate data aggregation to reduce the power consumption during transmission of a large amount of data between a large number of nodes. Visualization of collected data from the Wireless Sensor Networks using statistical and user-friendly methods such as tables and line graphs through a dedicated webpage or a GUI window. A software that could be used to monitor the weather conditions based on the sensors. The software would have self-learning and self-correcting skills to improve its prediction accuracy as it works. Creation of an index to categorize the various air pollution levels to represent the seriousness of air pollution meaningfully. Intelligent monitoring service by mounting sensor node on Quadcopter. Generation of reports daily or monthly and real-time notifications during severe air state pollution for use by appropriate authorities.

Table 3 to Table 6 shows the various range of values for temperature, humidity, carbon monoxide, and carbon dioxide concentration. The tables are represented in the following manner

**Table 3. Different ranges of temperature**

| Range                | Description          |
|----------------------|----------------------|
| 5 ° to 32 ° Celsius  | Ambient Temperature  |
| <= 5 degree Celsius  | Low Temperature      |
| >= 50 degree Celsius | High Temperature     |

**Table 4. Different ranges of humidity**

| Range          | Description         |
|----------------|---------------------|
| 10 to 90 percent | Ambient Humidity    |
| <= 10 percent    | Very Dry Climate    |
| >= 90 percent     | Too much Perspiration |
### Table 5. Different ranges of carbon dioxide concentration

| Concentration | Description |
|---------------|-------------|
| 250-350 ppm   | Usual amount of carbon dioxide in the background |
| 350-1,000 ppm | Congested indoor population with less space for air circulation |
| 1,000-2,000 ppm | Headache and nauseous feeling |
| 2,000-5,000 ppm | Irritation, the person feels dizziness, sleepy |
| 5,000 ppm     | The maximum limit for an employed person at his job location |
| >40,000 ppm   | Lack of oxygen flows into the blood, which may be fatal for the person. |

### Table 6. Different ranges of carbon monoxide concentration

| Concentration | Description |
|---------------|-------------|
| Nine ppm      | Extended exposure to CO |
| 35 ppm        | Eight hours exposure to CO |
| 800 ppm       | Person dies within 2 to 3 hrs. |
| 12,800 ppm    | Person dies within 1 to 3 minutes |

## 4. RESULTS AND OBSERVATIONS

The values obtained from the three sensors are stored as a text file. CSV format in an SD Card. The SD Card Module is used to read the data transfer from the receiver to the file form. The file is then imported to the server using the JSON and Node.js platforms. The IDE used in this case is Node-Red to develop the code. The GUI and moving average algorithm are used to find the optimized output and displayed using a GUI in real-time. Fig. 4 (a) shows the graphical representation of data collection of various sensors, and Fig. 4 (b) shows the remotely monitored data logging and storing in the system.

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**Fig 4:** (a) GUI based display of the Maximum, Minimum, and Average values from the Temperature, Humidity, CO₂, and CO Sensors, and (b) Remotely data logged into the system

The dynamic model test prototype is shown in Fig. 5. While in motion with the prototype mounted on it, the Quadcopter is acquiring the sensors' environmental data. The deodorant spray containing gases is used for testing the workability of the sensors. When the Sensor module is on quadcopter flight mode, it needs to offset as the air above is disturbed to a certain extent due to the Quadcopter propeller's rotation. Then the wireless communication is used to give real-time data. However, with a better trans-receiver, the range of Quadcopter with the module could be increased.
The DHT11 sensor was used to measure the temperature and humidity level in the atmosphere. The values are taken live and monitored through the controller. Fig.6 (a) and Fig.6 (b) plots show the humidity and temperature data collected during the flight mode. Either adding water causes the deviation to deviate the humidity, containing moisture, and bringing candle flame near the sensor to increase the temperature. The result obtained in the humidity and temperature plots is adding water or getting candle flame near it.

Fig.7 Test result of (a) Carbon Dioxide and (b) Carbon Monoxide Concentration of the sensor module
The Carbon Monoxide sensor was used to measure the carbon monoxide concentration in the atmosphere. The values are taken in real-time and displayed in the COM monitor of Arduino. Wireless Transmission is used for the transmission of these values into the ground station. The deviation is caused by deodorant body spray, which contains various gases and affects air constitution when sprayed on the sensor. The plot is shown in Fig.7 (a) has the peak is due to the deodorant sprays.

The same effect was observed by using the MQ-135 sensor for the carbon dioxide concentration in the atmosphere. The sensor is exposed to deodorant spray and noticed the peak in the plot shown Fig.7 (b) because of the concentration of CO₂ present in the Environment.

5. CONCLUSION

The Quadcopter and Data Acquisition Module consisting of Sensors integrated to do one complete autonomous module. The Environment and weather monitoring is executed by the Data Acquisition module and sent to the Host on the ground through a communication channel. The communication channel uses a UHF band for communication, and a server has been developed to include the data and show them graphically in the server in real-time. The Quadcopter can be called a Mobile Aerial Platform for Monitoring Purposes. These modules work simultaneously and intelligently to monitor the various parameters that shall enable the user to take the required actions.

REFERENCES

[1] D. Mage, G. Ozolins, P. Peterson, et al., "Urban air pollution in megacities of the world," Atmospheric Environment, vol. 30, no. 5, pp. 681–686, 1996.
[2] Tan, Si Ying, and Araz Taeihagh. "Smart city governance in developing countries: A Systematic literature review." sustainability 12.3 (2020): 899.
[3] Gupta, K., & Hall, R. P. (2017, May). The Indian perspective of smart cities. In 2017 Smart City Symposium Prague (SCSP) (pp. 1-6). IEEE.
[4] A. Seaton, D. Godden, W. MacNee, and K. Donaldson, "Particulate air pollution and acute health effects." The Lancet, Vol. 345, No. 8943, pp. 176–178, 1995.
[5] H. Mayer, "Air pollution in cities," Atmospheric Environment, vol. 33, no. 24-25, pp. 4029–4037, 1999.
[6] P. S. Kanaroglou, M. Jerrett, J. Morrison et al., "Establishing an air pollution monitoring network for intra-urban population exposure assessment: A location-allocation approach," Atmospheric Environment, vol. 39, no. 13, pp. 2399–2409, 2005.
[7] Di Francesco, M., Das, S. K., & Anastasi, G. (2011). Data collection in wireless sensor networks with mobile elements: A survey. ACM Transactions on Sensor Networks (TOSN), 8(1), 1-31.
[8] Shakhatreh, H., Sawalmeh, A. H., Al-Fuqaha, A., Dou, Z., Almaita, E., Khalil, I., & Guizani, M. (2019). Unmanned aerial vehicles (UAVs): A survey on civil applications and key research challenges. IEEE Access, 7, 48572-48634.
[9] Alsambhi, S. H., Ma, O., Ansari, M. S., & Almalki, F. A. (2019). Survey on collaborative smart drones and internet of things for improving smartness of smart cities. IEEE Access, 7, 128125-128152.
[10] Simic Milas, Anita, Arthur P. Cracknell, and Timothy A. Warner. "Drones—the third-generation source of remote sensing data." (2018): 7125-7137.
[11] Yin, N., Liu, R., Zeng, B., & Liu, N. (2019, April). A review: UAV-based Remote Sensing. IOP Conference Series: Materials Science and Engineering (Vol. 490, No. 6, p. 062014). IOP Publishing.
[12] Description of F450 Quadcopter used for the prototype. (Online) Available: https://dronepedia.xyz/dji-f450-quadcopter-review/
[13] *MQ-135 Sensor for Air Quality Detection*. (Online): Available: [www.olimex.com/Products/Components/Sensors/SNS-MQ135.pdf](http://www.olimex.com/Products/Components/Sensors/SNS-MQ135.pdf)

[14] *DHT11 Sensor*. (Online): Available: [www.sparkfun.com/datasheets/Sensors/Temperature/DHT11.pdf](http://www.sparkfun.com/datasheets/Sensors/Temperature/DHT11.pdf)

[15] *MQ-7 Sensor Carbon Dioxide Level Detection*. (Online): Available [https://www.sparkfun.com/datasheets/Sensors/Biometric/MQ-7.pdf](https://www.sparkfun.com/datasheets/Sensors/Biometric/MQ-7.pdf)

[16] *Transmitter*. (Online): Available: [www.nexrobotics.com/images/downloads/ST-TX01-ASK.pdf](http://www.nexrobotics.com/images/downloads/ST-TX01-ASK.pdf)

[17] *Receiver*. (Online): Available: [www.nex-robotics.com/images/downloads/ST-RX04-ASK.pdf](http://www.nex-robotics.com/images/downloads/ST-RX04-ASK.pdf)