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Thème

Design of Air Quality Monitoring Quadrotor

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Dedication

J'ai le grand plaisir de dédier ce modeste travail:

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Abstract

In recent years, poor air quality has been causing lethal risks to human health. It is necessary to monitor it. This work presents the design of a quadrotor prototype for outdoor air quality monitoring. Starting with the assembly of the different components, the configuration and the control of the drone. The second part of the project consists of the design and implementation of an air quality monitoring system that is the payload of the drone, using several sensors that measure the concentrations of the main air pollutants. This system sends these measurements to the ThingSpeak IoT cloud via the Gateway. The estimation of the air quality category is done by fuzzy logic and the result will be displayed on the server interface. This method gave satisfactory results compared to the conventional method.

Keywords: Unmanned aerial vehicle, Air quality monitoring, Air quality index, Fuzzy logic, Pollution.

Résumé

Ces dernières années, la mauvaise qualité de l'air a entraîné des risques mortels pour la santé humaine. Il est nécessaire de la surveiller. Ce travail présente la réalisation d'un prototype de quadrotor pour la surveillance de la qualité de l'air extérieur. Le contrôle du vol du drone et la planification de la mission sont gérés par le logiciel QGroundControl. Les informations des capteurs sont reçues par la passerelle vers le cloud IoT ThingSpeak, où elles sont évaluées. Nous avons estimé la qualité de l'air en utilisant une approche moderne qui est la logique floue. Cette méthode a donné des résultats satisfaisants par rapport à la méthode conventionnelle.

Mots clés: Drone, La surveillance de la qualité de l'air, Indice de la qualité de l'air, Logic floue, Pollution.

ملخص

في السنوات الأخيرة، ادت جودة الهواء السيئة إلى مخاطر قاتلة على صحة في السنوات الأخيرة ، أدت نوعية الهواء الرديئة إلى مخاطر تهدد صحة الإنسان. من الضروري مراقبته. يقدم هذا العمل تصميم نموذج أولي طائرة بدون طيار لمراقبة جودة الهواء في الهواء الطلق. بدءًا من تجميع المكونات المختلفة وتكوين الطائرة بدون طيار والتحكم فيها. يتكون الجزء الثاني من المشروع من تصميم وتنفيذ نظام مراقبة جودة الهواء وهو حمولة الطائرة بدون طيار ، باستخدام عدة أجهزة استشعار تقيس تركيزات ملوثات الغلاف الجوي الرئيسية. يرسل هذا النظام هذه القياسات إلى ThingSpeak IoT cloud عبر Gateway تم تقدير فئة جودة الهواء من خلال منطق ضبابي وسيتم عرض النتيجة على واجهة Server . أعطت هذه الطريقة نتائج مرضية مقارنة بالطريقة التقليدية.

كلمات مفتاحية: طائرة بدون طيار ، مراقبة جودة الهواء ، مؤشر جودة الهواء ، منطق ضبابي ، التلوث.

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Acronyms

AQI Air Quality Index

AQMs Air Quality Monitoring Systems

BLDCBrushless Direct Current motors

CCK Counter Clock Wise

CK Clock Wise

CO Carbon Monoxide

DC Direct Current

DOF Degrees of Freedom

ESC Electronic Speed Controller

EPA Environmental Protection Agency

FAA Federal Aviation Administration

FIS Fuzzy Interface System

GIS Geographical Information Systems

GPS Global Positioning System

ISM Industrial Scientific and Medical Frequency

IoT Internet of Things

LNA Low Noise Amplifier

MALE Medium Altitude long Endurance

NO2 Nitrogen Dioxide

O3 Trioxygen

PA Power Amplifier

PID Proportional Integral Derivative

PM Particle Matters

PPM Pulse Position Modulation

PWM Pulse Width Modulation

QGC QGroundControl

RF Radio Frequency

RC Radio Controlled

SO2 Sulfur Dioxide

SPI Serial Peripheral Interface

UAS Unmanned Aerial system

UAV Unmanned Aerial Vehicle

UV Ultra Violet

WLANs Wireless Local Area Network

WSN Wireless Sensor Network

GENERAL INTRODUCTION

The growth of industrial infrastructure and transportation has an impact on the earth's climate in recent years, contributing to global warming. Human and animal life are both endangered by bad air quality. Air quality must be monitored in order to make decisions that protect the environment while also improving quality of life and human health.

Recently, the study of unmanned aerial vehicles (UAVs) has progressed significantly in recent years. UAVs are now widely used for a variety of purposes, including surveillance, military and commercial missions, industrial applications, and environmental monitoring.
Among the advantages of using UAVs for air surveillance is the ability to cover large areas due to their movability in several dimensions compared to terrestrial systems, and their flexibility in avoiding obstacles and collisions.

In this project, we design an air quality monitoring drone, starting by citing the different air monitoring systems and more specifically air quality monitoring drones as well as the history of drones and their state of the art. Next, we move on to the quadrotor assembly and configuration stage using the QgroundControl software. Then, we will develop a modern method for estimating the air quality index using fuzzy logic. Finally, we will test our air quality monitoring drone in several environments to evaluate its performance.

This thesis will be divided into four chapters, each of which is briefly described in the following paragraph:

- **Chapter 1:** discusses air quality monitoring systems in general, their structure, and the air quality index estimate technique, as well as the development history of air quality monitoring drones and their architecture.

- **Chapter 2:** covers the state of the art in UAVs, as well as the classification of aerial systems according to several criteria.
- **Chapter 3:** explains the steps of quadrotor assembly, calibration and configuration by the software QgroundControl.
- **Chapter 4:** presents the air quality monitoring system. We describe the different components used, the process of collection and transfer of measurements to the cloud, and the procedure of estimation of the air quality index by fuzzy logic.
- **Chapter 5:** presents our air quality monitoring drone with the different tests performed and the display of the results in a geographic information system.

CHAPTER

1

AIR POLLUTION CONTROL SYSTEMS

1.1 Introduction

Air quality has become an area of interest for engineers, researchers, and the whole world. Various air pollutants, such as plant smoke, fossil fuels and gaseous pollutants have a fatal effect on human health. These include respiratory, cardiac and cerebrovascular diseases. As technology grows, air quality control systems are very effective at monitoring air quality and protecting the health of living creatures. This chapter will define what constitutes air pollution and how it increases over time, then we explain the role of air quality monitoring systems in reducing such harmful effects and expanding on UAV air quality monitoring systems by explaining their structure and how beneficial they are to our environment.

1.2 Air pollution

1.2.1 Definition

Air pollution refers to any pollutant present in the atmosphere, composed of solid particles or gases that can affect negatively our human health and harm the environment, such as (damaging the ozone layer or causing global warming) [1].

It is mostly a term used to designate the massive emissions of gases or particles linked to human activities, such as transport or industry in particular. Ozone for example, comes from the transformation of oxygen in the face of other gases and with high temperature. Once in the atmosphere, ozone can become smog after being mixed with other atmospheric pollutants. A very harmful brownish fog that can sometimes be seen hanging over large cities.

The most notorious air pollution events have often been associated with dramatic atmospheric visuals such as smoke surging from industrial areas, smog hanging over large cities, dead trees from acid rain, holes in the ozone layer, etc [2].

1.2.2 History of air pollution

Historically, air pollution started with the discovery of fire and human exposure to chemicals produced during biomass burning (combustion of wood and vegetation) in poorly ventilated locations where concentrations could reach levels that are harmful to human health. During the 19th century, the Industrial Revolution led to the emission of significant amounts of air pollutants via the combustion of a variety of fossil fuels [3].

During the 1950s, a new type of air pollution appeared due to the use of big cars to move around, combined with industries (power plants, refineries, port activities, etc). It led to the formation of secondary pollutants such as ozone and fine particles. This type of air pollution was the result of atmospheric chemical reactions.

Household air pollution has been declining worldwide since 1990 as liquefied petroleum gas and renewable sources of energy come to replace biomass (wood, straw, etc.) fuels for household cooking and heating [4].

By the 20th century, people living in many industrialized urban centers grew weary of smoky air. Where billowing smoke stacks had marked the prosperity, discontent mounted toward the acrid soot that darkened surfaces, obscured sight lines, or dried throats making it hard to breath [5].

Polluted air was responsible in 2015 for 6.4 million deaths worldwide: 2.8 million from household air pollution and 4.2 million from ambient air pollution [4].

According to the World Health Organization (WHO), each year air pollution is responsible for nearly seven million deaths around the globe. Nine out of ten human beings currently breathe air that exceeds the WHO's guideline limits for pollutants, with those living in low- and middle-income countries suffering the most.

(A) Nuclear power plant

(B) Industrial area

Figure 1.1: Air pollution sites

1.2.3 Pollutants

Air pollution is a major environmental problem caused by a number of pollutants visible particles like soot or smoke and invisible ones such as Sulfur dioxide (SO2) and carbon monoxide (CO).
usually pollutants are separated into two main types primary and secondary pollutants a distinction is generally made between them:

- **Primary pollutants**: released directly from a source, which can be natural (volcanic eruptions, fires) or of anthropogenic origin such as carbon dioxide (CO2), sulfur or heavy metals).
- **Secondary pollutants**: not directly emitted from a source, but forms when other primary pollutants react in the atmosphere such as (ozone, which is formed when hydrocarbons (HC) and nitrogen oxides (NOx) combine in the presence of sunlight; NO2, which is formed as NO combines with oxygen in the air and acid rain, which is formed when sulfur dioxide or nitrogen oxides react with water) secondary pollutants can be more dangerous.

The two most prevalent types of air pollution:

- **Smog** (sometimes referred to as ground-level ozone) occurs when emissions from combusting fossil fuels react with sunlight.
- **Soot** (also known as particulate matter) is made up of tiny particles of chemicals, soil, smoke, dust, or allergens—in the form of either gas or solids—that are carried in the air. They have a similar source. Both come from "cars, trucks, factories, power plants, etc".

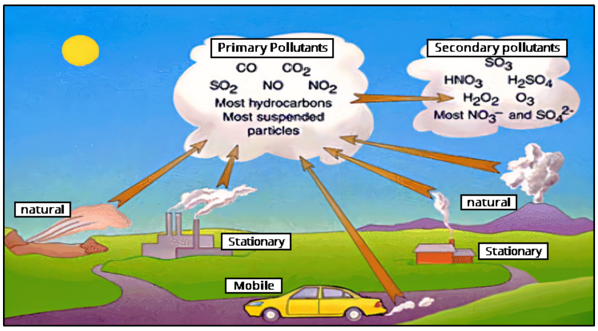


FIGURE 1.2: Types and sources of air pollutants

1.2.4 Effects of air pollution

The effects of air pollution on the human body vary depending on the type of pollutant and the length and level of exposure as well as other factors, including a person's individual health risks, age and the cumulative impacts of multiple pollutants [6].

These effects can vary, ranging from simple symptoms like coughing and the irritation of the respiratory tract to more dangerous ones like asthma and chronic lung diseases.

Skin problems and irritations can develop due to prolonged exposure to several air pollutants, and a variety of cancer forms may develop after inhaling air contaminants. Do not neglect potential diseases caused by air pollution.

Air pollutants that have serious negative effects on the human health can be classified as toxic and non-toxic [1].

- **Toxic pollutants**: can be separated in two types:
  Carcinogenic: (asbestos, vinyl chloride (VC), benzene, ethylene dibromide (EDB), arsenic oxide,pesticides/insecticides/herbicides,etc).
  Non-Carcinogenic: (lead, carbon monoxide, ammonia, acetone).

- **Non-toxic pollutants**: These pollutants can still asphyxiate by oxygen depletion, therefore they are still not safe in certain quantities, like carbon dioxide and methane.

Table 1.1 resumes the effect of the major pollutants.

Pollutant	Effects
O3	Lung disease
PM2.5 and PM10	Lung disease
CO	Fatigue, headache, Impaired, vision, Coma, Brain damage ,death
NO2	Adverse effects on the respiratory system
SO2	People with asthma, children, and older adults are the groups most at risk

Table 1.1: Air pollutants and effects

1.3 Air Quality Monitoring Systems (AQMs)

The development of technical monitors and telemetric systems is advancing day by day. Thanks to the environmental monitoring systems, researchers and engineers have easy access to environmental data [7].
Modern environmental monitoring and surveillance systems can collect data and information at different levels on the environmental state and air quality more accurately and quickly.

1.3.1 Air quality index (AQI)

With several types of pollutant sensors, we can monitor outdoor air quality by measuring the concentration of each pollutant. The Environmental Protection Agency (US EPA) proposes to use the level of five pollutants: O3, CO, NO2, SO2 and PM to measure outdoor air quality [8].
The Air Quality Index (AQI) is a number used by government agencies to analyze air quality at a specific location. The calculation of this index requires a concentration of each pollutant. The values of AQI are divided into ranges, and each range is assigned with a descriptor and a color code, and the pollutant with the highest concentration (or highest AQI value) is considered as the “responsible pollutant” [9].
The AQI value can be simply calculated for each pollutant using following equation [9] [8]:

$$I_p = (C_P - BP_{Lo}) * \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} + I_{Lo} \tag{1.1}$$

where:

I_p = the index for pollutant p.

C_P = the round concentration of pollutant p.

BP_{Hi} = the breakpoint that is greater than or equal to C_P.

BP_{Lo} = the breakpoint that is lesser than or equal to C_P.

I_{Hi} = the AQI value corresponding to BP_{Hi}.

I_{Lo} = the AQI value corresponding to BP_{Lo}.

Table 4.6 shows the six levels of health and the breakpoints for the AQI:

Breakpoints for the AQI								
O3 (ppm) 8-hour	O3 (ppm) 1-hour	PM10 (ug/m^3)	PM2.5 (ug/m^3)	CO (ppm)	SO2 (ppb) 1-hour	NO2 (ppb) 1-hour	AQI	Category
0.000-0.054	-	0.0–12.0	0- 54	0.0- 4.4	0-35	0 - 53	0 - 50	Good
0.055-0.070	-	12.1–35.4	55- 154	4.5-9.4	36-75	54-100	51 -100	Moderate
0.071-0.085	0.125-0.164	35.5–55.4	155-254	9.5-12.4	76-185	101-360	101-150	Unhealthy for Sensitive Groups
0.086-0.105	0.165-0.204	55.5-150.4	255-354	12.5-15.4	186-304	361-649	151-200	Unhealthy
0.106-0.200	0.205-0.404	150.5-250.4	355-424	15.5-30.4	305-604	650-1249	201-300	Very unhealthy
-	0.405-0.504	250.5-350.4	425-504	30.5-40.4	605-804	1250-1649	301-400	Hazardous
-	0.505-0.604	350.5-500.4	505-604	40.5-50.4	805-1004	1650-2049	401-500	Hazardous

TABLE 1.2: Breakpoints for the AQI

1.3.2 Architecture of a modern environmental monitoring and information system

The primary goal of the monitoring system is to access and monitor the data collected online directly and quickly. For the planning of operations, which requires modern technology. The system should include [7]:

- Data collectors: sensors and monitors.
- Data transfer systems and data quality assurance/control procedures and data bases included emission and discharge modules.
- Statistical and numerical models (included air pollution dispersion models and meteorological forecast procedures).
- Geographical Information Systems (GIS) [10]- [11].
- Data distribution systems and communication networks for dissemination of results to "outside" users.

Figure 1.3 depicts the main components of the integrated environmental monitoring and information system.

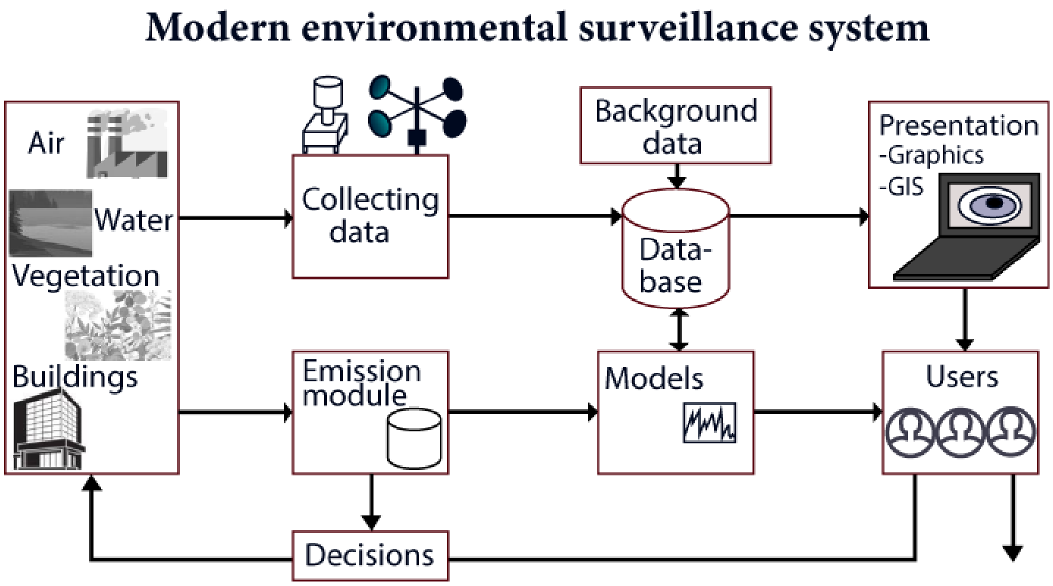


FIGURE 1.3: Principal structure of a modern environmental monitoring and information system

1.3.3 Components of a environmental monitoring and information system

Sensors Nodes

The sensor nodes measure the concentration of the main air pollutants and send the acquired data to the web server [12].The sensor types and number of sensors included in the sensor node varies significantly in each implementation [8], and each type of sensor has unique characteristics. For air pollutants it is important to decide whether one wants to measure to obtain a point measurement or take an integrated sample over a distance or a volume [7].

Sensors Network

Wireless networks have a significant role to play. This is a promising infrastructure for the collection of information in the surveillance zones and its transmission to the server for processing and action [8] [13]. There are three types of networks: wireless local area networks (WLANs), mobile networks and cell phone networks.
Wireless Sensor Networks (WSN) have been used to control indoor and outdoor air quality; because it requires fewer components and, as a result, consumes less energy. Each wireless transceiver transmits the information it has received from the sensors to the gateway. The gateway then takes data and transmits it to a central base station or data base.

Data processing

The main task is to evaluate the air quality from the sensor data. We must therefore analyze this information to calculate the air quality index (AQI). Two main blocks have responsibility for storage and presentation [12]:

- **Database**: This block is responsible for storing the measured data. Each record stores information about each sensor, including the sensor type and measured value, geographic coordinates, date and time, node identification, etc.

- **Web server**: The primary purpose of this block is to provide the system web user interface and receive data from all nodes and store it in the database, then calculate the Air Quality Index (AQI) based on the sensors data.

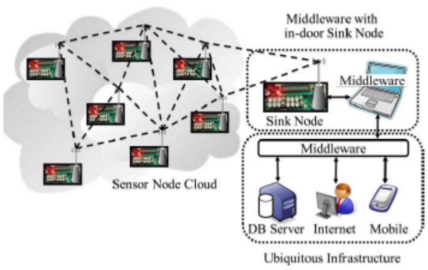


FIGURE 1.4: Network configuration for remote indoor monitoring

1.3.4 Different air quality monitoring systems technologies

There are two potential technologies constitute a robust platform for the development of AQM systems: wireless sensor technologies (WSN) and Internet of Things (IoT) [14].

IoT-based outdoor air quality monitoring systems

The structure consist mainly of four parts: monitoring system, data storage, data analytics services, and data visualization system [14].
The monitoring system have various sensors, MCUs, and communication systems. The data collected through a sensing unit is then stored in a data storage system that can be either online storage or physical storage. Data analysis services may also be used to analyze the impact of pollutants on target premises. The visualization system also assists end-users in obtaining instantaneous updates on outdoor air quality levels. Figure 1.5 describes the general architecture of IoT-based outdoor air quality.

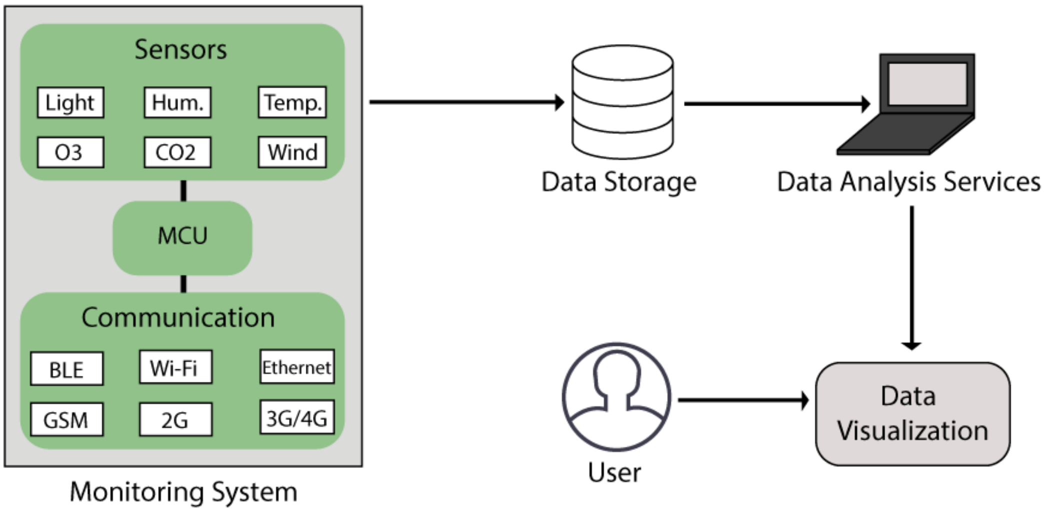


FIGURE 1.5: General architecture of Internet of Things (IoT)-based outdoor air quality monitoring systems

Outdoor Air Quality Monitoring System Based on ZigBee Wireless Sensor Network

The WIFI (IEEE 802.11) is a common protocol used in WLANs, and as such, it has some drawbacks: the allowed communication distance is shorter and it may have more interference because many WLANs are used in the real world.
The researchers have adopted an extended star type WSN for air quality monitoring [13]. After detection of the sensors, there is a transmission of data from each wireless transceiver to a

gateway. Then that gateway will pass them on to a central base station.
The number of gateways was determined based on the range and signal strength. For example, the ZigBee protocol/transceiver can be used due to its low-power usage and reasonable communication range (up to 1000 m) [8], and the base station or ZigBee coordinator receives data from ZigBee end nodes at regular intervals [15].
The ZigBee-based WSN is adopted for real-time air quality monitoring for three potential structures: stars, meshes and hierarchies. Thus, WSN based on ZigBee is a great option for outdoor air quality monitoring.

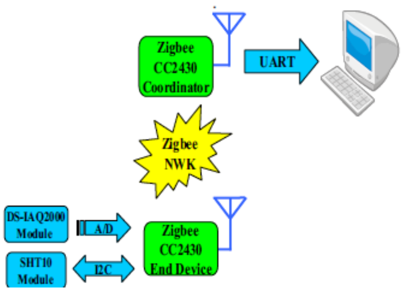


FIGURE 1.6: General architecture of outdoor AQM System Based on ZigBee Wireless Sensor Network

1.4 UAV air quality monitoring systems

In recent years, researchers and engineers have proposed and developed air quality monitoring systems using unmanned aerial vehicles in combination with the wireless sensor network to measure the air quality index AQI at different locations. They are also referred to as UAV-based air quality sensing systems AQMs, UAV-based air quality monitoring systems or 3D air quality monitoring systems [16].

1.4.1 Development of UAV quality monitoring systems

In the latest seven years, more than 21800 papers have been written on this solution. The first researchers who worked on this idea were Wenqian Zang , Jiayuan Lin in and Yuzhe Yang in. by analyzing the interpretation of images in southwest china [16]. They prove the effectiveness of drones rather than using satellite or manned aircraft remote sensing, which is too costly and time consuming [16] [17].
Anatoli danilov proposed a Gas Sensing System based on the low-cost sensors[16].Where a GSS was developed and mounted on the Small DJI hexacopter UAV to build 3D models of the

pollution of the atmospher [17].

There are many air quality monitoring projects using drones: UAV's atmosphere monitoring, UAV's automatic AQM, Smart community and UAV-based AQM,Automatic UAV-based AQM,...[16].

1.4.2 UAV air quality monitoring systems structure

As we explained in Architecture, our system is composed of many layers four to be precise, starting with the sensing layer to the transmission layer then the processing layer and ending with the presentation layer. The sensing layer is responsible for the collect of air quality data in real-time. It's carried out by sensing devices mounted on our mobile UAV. The transmission layer enable's bidirectional communications creating a two way data transfer between the sensing layer and the processing layer. Using a wireless sensor network as the data transmission platform. The processing layer is responsible for recording the data from the sensing layer and sending the processing results to the presentation layer. It is implemented in a cloud server where real-time processing and big data analysis are supported. Then lastly, the presentation layer provides valuable information included in a official website so users can compare the real-time results to the desired ones.

Figure 1.7 describes the structure of UAV air quality monitoring systems.

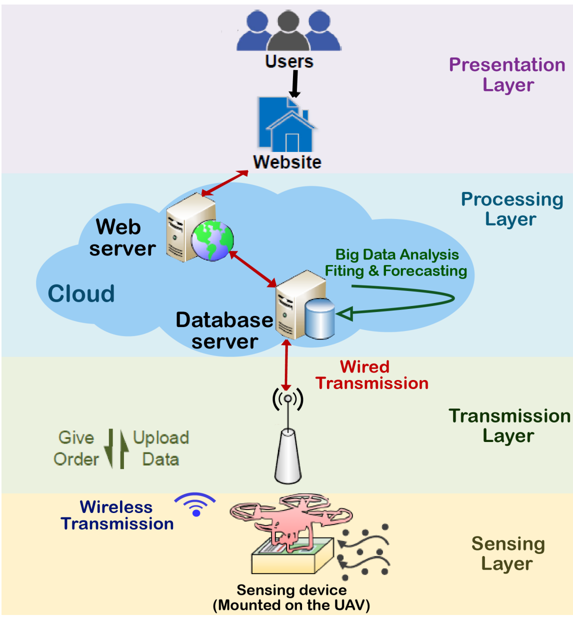


FIGURE 1.7: Layers of UAV air quality monitoring systems

1.5 Conclusion

In this chapter, we briefly presented the history of air pollution and the main air pollutants and their effects. We have also shown the modern architecture and the different technologies of environmental monitoring systems. Finally, we have seen the development of the UAV's air quality monitoring systems by drone with their structure.

CHAPTER

2

STATE OF THE ART

2.1 Introduction

Unmanned aerial vehicles (UAV) also called drones are in constant development, used in multiple fields for a variety of applications (wireless identification, sensing platform, military missions, etc.) UAVs are perfect for Supervision and Monitoring due to their agility and speed.

As drones are increasingly used, humans are bond to interact with them more often than ever, therefore it is important to understand how UAVs work and how they are structured.

This chapter will cover the different types of UAVs, then it will focus on the structure and dynamic movements of quad-rotors.

2.2 Drones (Unmanned Aerial Vehicle)

"Drone" is a term that refers mainly to "Unmanned Aerial Vehicles" (UAVs), or what the Federal Aviation Administration (FAA) assigns to as an "Unmanned Aerial System" (UAS).

The drone family is not composed solely of flying objects. It includes every vehicle with no pilot on board: terrestrial drones, marine drones, submarine drones, even subterranean drones imagined in the form of fat mechanical moles. Any kind of vehicle or piloted engine can be

"Dronized" [18].

The unmanned aerial vehicles (UAV) can either be controlled by a human pilot who sends the commands from a control station (remotely controlled) or autonomously by a system integrated on the physical drone.

2.3 Classification of UAV

Drones can be classified according to several criteria: size, missions, range and endurance and wing types.

2.3.1 Classification according to size

Very Small UAVs

They are extremely lightweight with a very small size launched by hand, their dimensions are 30-50cm long (the size of an insect), generally, they are used for espionage and biological warfare. They use flapping wings to mimic flying insects or birds and use more or less conventional aircraft configurations or rotating wings for micro systems [19]. The US Aurora Flight Sciences Skate and the Australian Cyber Technology CyberQuad Mini are examples of very small UAVs.

(A) Aurora Skate UAV

(B) CyberQuad UAV

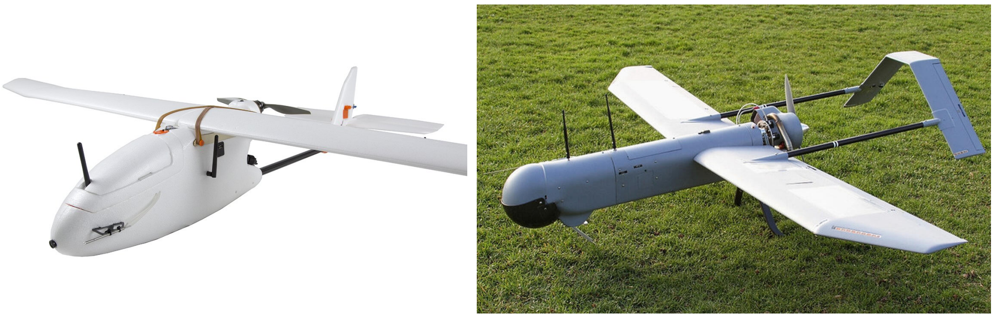
FIGURE 2.1: Very small UAVs

Micro and Nano UAVs(MAV and NAV UAVs)

They have a range of less than 1 km and a maximum flight altitude of approximately 100 m and average endurance. Different kinds of Micro and Nano aerial vehicles attract various disciplines including aerospace, mechanical, electrical, and computer engineering [20].

Small UAVs

Small drones are slightly larger, their dimensions are from 50 to 200cm long. They usually have either a fixed-wing or a rotating wing and can be launched manually. Because of their small size, the majority of small drones fly at altitudes close to 125 meters and with speeds lower than 50 meters per second. Examples: RQ-11 Raven UAV and AAI RQ-7 Shadow UAV.



(A) RQ-11 Raven UAV

(B) (b) AAI RQ-7 Shadow UAV

FIGURE 2.2: Small UAVs

Medium UAVs

The dimensions of the medium drones are up to two meters long with a wingspan between five and ten meters. They are designed to fly at altitudes below than 5500 meters, their speeds can go up to 125 meters per second. These drones are heavy compared to the small drones so they require to be launched by other methods.

FIGURE 2.3: Medium UAVs

Large UAVs

Large UAVs are perfect for military operations due to their high capacity, they can fly at altitudes higher than 5500 meters with speeds exceeding 125 meters per second for a long-range due to their integrated system and sophisticated electronic payloads (radar, communication systems, sensors, etc).

FIGURE 2.4: Large UAVs

2.3.2 Classification according to Range and Endurance

Close range UAVs

Close range UAVs are mostly used for surveillance and reconnaissance missions. They have a range of 10 to 30 km and can be sustained in the air for 2 to 4 hours.

Short range UAVs

These drones are capable of flying up to 150 km and remain airborne for up to 6 hours. They are generally used for the same tasks as close-range drones because they are more powerful in terms of range and endurance.

Mid-range endurance UAVs

Medium range drones are the most efficient in terms of range and endurance. They can fly as far as 650 km from the pilot-man or control station, and stay in the flight for up to 12 hours. These UAVs are intended for longer surveillance missions.

Medium-altitude long-endurance UAVs (MALE)

They are capable of flying at an altitude of 9 000 to 14 000 m and have an endurance of 24 to 48 hours [21] [22].

High Altitude Long Endurance UAVs (HALE)

HALE drones are able to fly up to 18 km altitude and carry out missions lasting more than 32 hours.

On the other hand, there is a classification proposed by Brooke-Holland, based on the weight of the drones [23].

Class	Type	Weight range
class I(a)	Nano drones	W ≤200g
class I(b)	Micro drones	200g<W≤2kg
class I(c)	Mini drones	2kg<W≤20kg
class I(d)	Small drones	20kg<W≤150kg
class II	Tactical drones	150g<W≤600kg
class III	MALE/HALE/Strike drones	W>600kg

TABLE 2.1: Proposed drones categorization by Brooke-Holland based on their weight

2.3.3 Classification according to wing and rotors

This figure shows the different types of UAVs classified based on their wings and rotors.

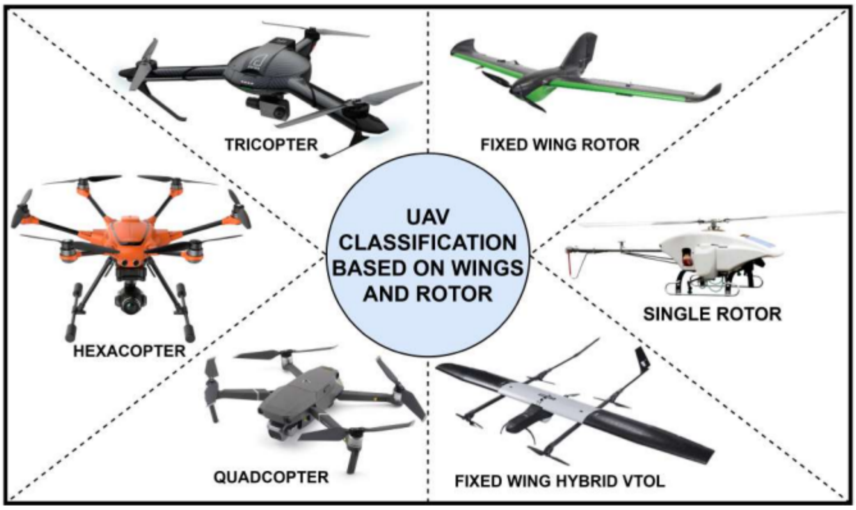


FIGURE 2.5: Classification of UAVs according to wings and rotors

Fixed wings UAVs

Instead of vertical rotors, this drone's shape resembles that of an aeroplane with fixed wings to provide lift. They only consume energy to fly not to hover, thus they are good for long flight periods due to their endurance, but they're also quite expensive [24].

Fixed-Wing Hybrid VTOL UAVs

They combine fixed-wing drone advantages with the ability to hover, take off, and land vertically. They are handy for a variety of purposes, including delivery. Consider the Amazon Go delivery drone.

Single Rotor UAVs

They are similar to helicopters, with one main rotor for flight control and a second on the tail. For long missions, they can be propelled by gas engines. Single-rotor drones are more efficient than multi-rotor drones because they have long blades that act like spinning wings and provide excellent performance, but they are more complicated and costly [25].

Multi-rotor UAVs

These drones feature more than two rotors, are easy to fly, and are inexpensive. Trirotor, quadrotor, hexarotor, and octarotor are the most common multi-rotor drones. The speed of rotation is affected by the larger of the rotor blades. As a result, a quadrotor outperforms an octarotor. They take a lot of energy to stay airborne, thus their range, endurance, and speed are restricted.

2.4 Quadrotor UAV

Quadrotors are Vertical Take-Off and Landing aerial vehicles used in a lot of fields starting from simply taking pictures or recording data and making geographic maps all the way to military operations.

The structure of a quad-rotor UAV is considered simple compered to its siblings (octa, hexa, etc), basically composed of four rotors attached to the ends of a symmetrical frame.

2.4.1 Quadrotor Structure

To prevent flight stability issues, the structure must be as rigid as feasible while also being as lightweight as possible. It should also be symmetrical in order to keep the UAV stable by ensuring that its center of gravity is as close to the structure's center as possible. As a result, stiffness and symmetry are required.

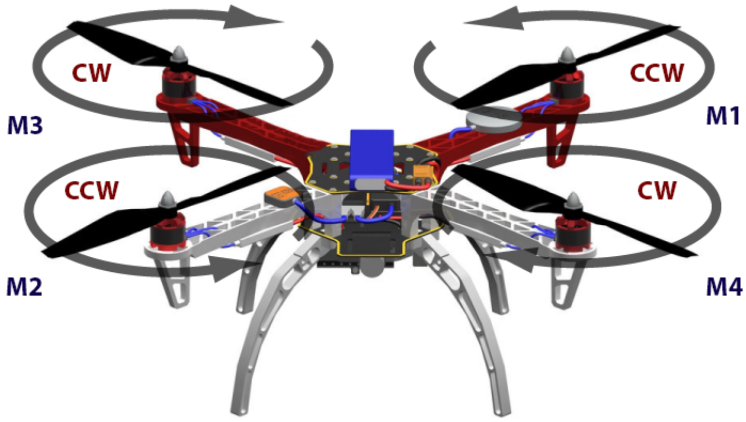


FIGURE 2.6: Quadrotor structure

2.4.2 Quadrotor components

A quad-rotor UAVs fundamental components are a main frame with four arms, each with four brushless motors attached to each arm [26][27], electronic speed controllers, a flight controller, propellers, an RC transmitter and receiver, and a battery. The anatomy of a quad-rotor is illustrated in the following figure:

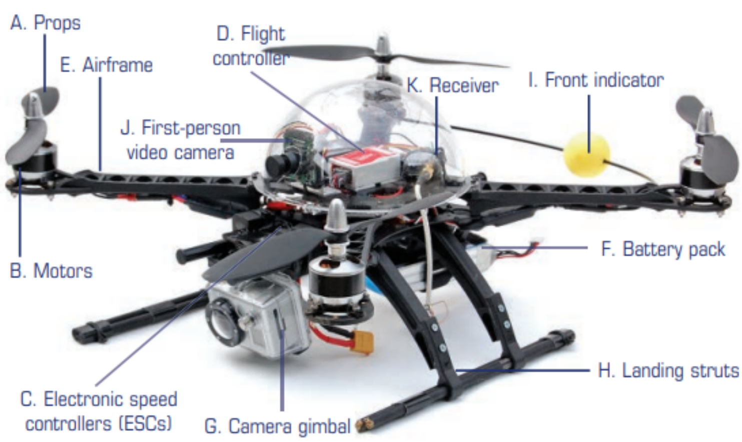


FIGURE 2.7: Components of a quadrotor

Frames

The frame is the chassis of the drone. It contains various hardware components, including the motors, flight controller, battery and other electronics. Typically, frames are made of plastic, fiberglass and carbon fiber[28].

FIGURE 2.8: Frame of a quad-rotor

Motors

Depending on the use and flight duration of the quadrotor, the power of the brushless motor is chosen accordingly. Brushless DC motors (BLDC) are one of the drone's most crucial components. Small DC gear motors are sufficient for small drones.

FIGURE 2.9: Brushless DC motor

Electronic speed controller (ESC)

They are used to control the speed and direction of the Brushless motors by controlling the current and voltage of each motor [29]. As a result, the drone can move in a variety of directions.

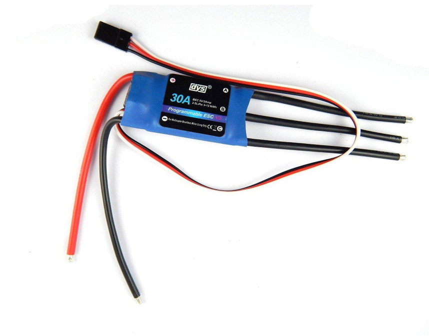


FIGURE 2.10: Electronic speed controller (ESC)

Propellers

The propeller works in the same way that wings do in flight. Propellers come in a variety of shapes and sizes. Quadrotor flight speed is affected by the size of their propellers, as previously stated. As a result, selecting the lightest and strongest propellers with the appropriate size is critical.

FIGURE 2.11: Different types of propellers

Flight Controller

The drone's brain is the flight controller. It features a variety of sensors that detect the drone's movement, including a gyroscope, accelerometer, and barometer. To operate the quadrotor, it gets information (signal) from the transmitter.

Cleanflight, Betaflight, and Mission planner are examples of software that can be used to configure the flight controller.

FIGURE 2.12: Flight controller pixHawk

Transmitter and Receiver

The radio transmitter is an electronic device that transmits commands wirelessly across a specific radio frequency using radio frequencies. When the drone takes to the air, the pilot sends commands to the drone via the transmitter, which the drone receives via the receiver and sends to the flight controller, then processes the signal and controls the drone [29].

FIGURE 2.13: Transmitter and Receiver of UAVs

Batteries

All of the quadrotor electronic components require power. The drone's flight time is influenced by the battery capacity. As a result, it's essential to select batteries that are both light and powerful. Lithium polymer batteries are commonly used.

FIGURE 2.14: Battery of UAVs

2.4.3 Movements of quadrotors

The quad-rotor is an aircraft lifted and propelled by four rotors. As its name indicates,as shown in the figure. Its movement is controlled by varying the speed of each rotor to change the force of lift and the torque.

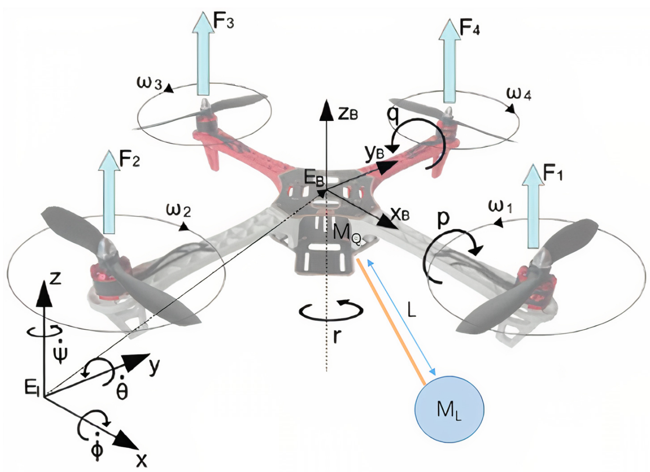


FIGURE 2.15: Degrees of freedom in Quad-rotor

The movement and flight of a quad-rotor is quite particular. The drone is defined in space by 6 degrees of freedom [30]. The vertical movement of ascend and descent is ensured with a coordinated speed of the four rotors at the same time. The difference in thrust between the front and rear motors produce a pitching torque, which controls the translation movement forward and backward. On the other hand, the left-right movement, is ensured by the difference in thrust between the rotors located on the left and on the right. Finally, for the yaw control of the system, it is the sum of the anti-torques produced by the four rotors, which defines the direction of rotation [31].

So basically There are four possible movements for a quad-rotor: thrust, yaw, pitch and roll.

The Pitch

The pitch is the translation in a forward or a backward motion and is generated by making two rotors in the front or the back high speed and the others facing it low causing the quad-rotor to tilt along the horizontal axes "y" the variation of the angle θ depends on the speed of the rotors.

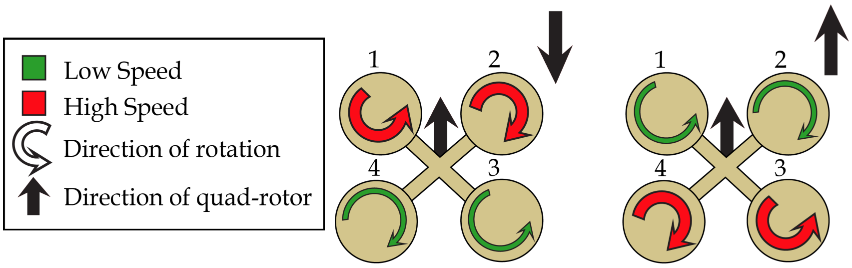


FIGURE 2.16: Pitch: Backwards or Forwards

The Roll

The Roll is the translation in the right or the left and is generated by making two rotors in the right or the left of our quad-copter high speed and the others facing it low causing the quad-rotor to tilt along the horizontal axes "x" the variation of the angle ϕ depends of the speed of the rotors.

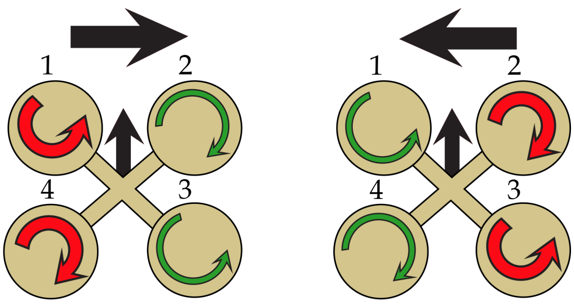


FIGURE 2.17: Roll: to the Right or Left

The Thrust

Its height of flight or the vertical translation up and down of the quad-rotor is the result of a coordinated high or low speed of all the rotors. It causes the quad-rotor to lift if it's high or go drop-down if it's low in the axis "z".

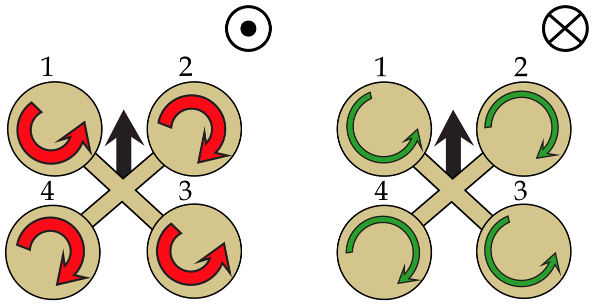


FIGURE 2.18: Thrust: lift up or drop down

The Yaw

Rotation around the "z" axis is called yaw in aeronautics. To change the yaw angle, it is necessary to vary the speed of rotation on the pair of rotors (1 , 3) and (2 , 4) depending on the desired angle on the yaw, basically changing the speed of the clockwise rotors making them high and the others low or the other way around.

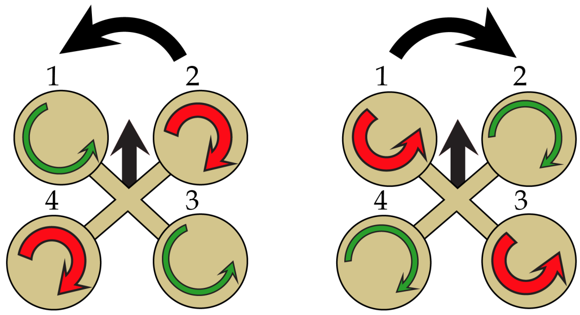


FIGURE 2.19: Yaw: Rotation to the left or to the right

We have three flight modes :

- **Vertical flight**: is simply the Thrust by lifting up or dropping down.
- **Stationary flight**: is when the force of lift and that of gravity are equal and opposite.
- **Translation flight**: is the navigation and translation over the horizontal axis. It is ensured based on tilting for pitching and rolling movements.

2.5 Conclusion

In chapter two, we have discussed the basics of UAVs and their classification based on various criteria, with a focus on quadrotors, their structure, components, and different movements. knowing all the basics about quadrotors we need to understand the different steps to assemble, configure and tune a UAV.

CHAPTER

3

ASSEMBLY AND CONFIGURATION OF A QUAD-ROTOR

3.1 Introduction

Air quality monitoring system is a device that calculates the concentration of different pollutant in the air using a flaying vehicle, in our case a "Quad-rotor" UAV. The design is made up of a mechanical and an electrical structure that are fused together by the flight controller. The process would be divided into four primary phases: the mechanical structure, the electronic structure, the calibration, and the configuration of our UAV .

This chapter will explain the electrical and mechanical structure of a quad-rotor followed by the different steps to assemble and configure our UAV ending it with a display of PID tuning and some flight preparation indications.

3.2 Quad-rotor mechanical structure

The main mechanical structure of the UAV is the frame. The steps of its assembly are the following:

We start by mounting every A2212 brushless motor on top of each arm, then we fix the arms on the main board of our dji f450 frame, at the end we close the frame using the upper board. Between the two boards is where the the electrical structures will be grouped, and the battery will be attached on top of our quad-rotor.

Due to lack of space on our main board and to increase the aesthetic, efficiency and safety of our structure we added a middle floor between the main board and the upper board to separate the power module from the flight controller.

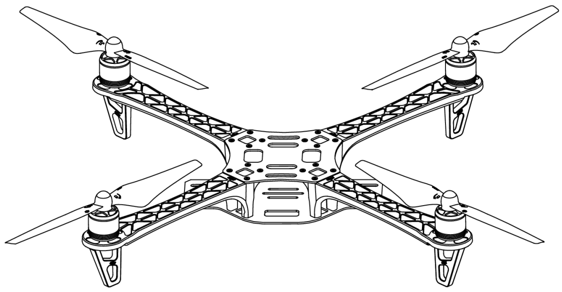


Figure 3.1: DJI f450 frame

3.3 Quad-rotor electrical structure

The Pixhawk mini 3DR is a flight controller usually setup with power module. The GPS and compass, receiver, switch and 8 channel PWM board are connected to the flight controller according to their respective port. The wiring of our electrical structure can be shown in Figure 3.2.

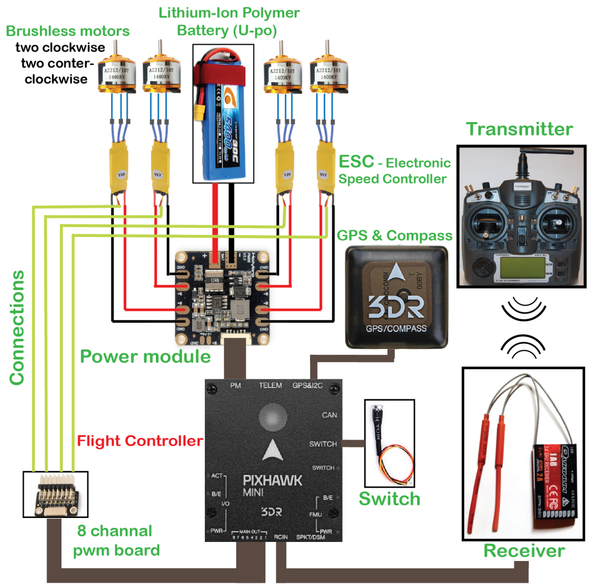


FIGURE 3.2: Electrical structure

The power module provides regulated power to the flight controller and ESCs (electronic speed controller's), it also sends information to the autopilot about the battery's voltage and current drawn.

The speed of each motor is controlled using ESCs, which are connected to an 8 channel pwm board linked to our flight controller. The receiver will be mounted on our main board to intercept all the commands sent by our transmitter.

3.4 UAV assembly

In this part we are going to explain the full assembly of the quadrotor frame DJI F450, and the electrical wiring of the components:

- **Attaching Motors:** Screwing the motors on top of skids and respecting the order on the air frame then making sure the direction of rotation of each two motors facing each other must be similar (clock wise or counter clockwise) making it able to perform any aerial movements: Thrust, Pitch, Roll, and Yaw.

- **Wiring of electronic speed controller's:** Fixing the ESC on the bottom part of each arm using zippers, then we link them to the motors using the BLDC Motor Connections. They are controlled by the flight controller, which adjusts the brushless motor speed via the servo connections.

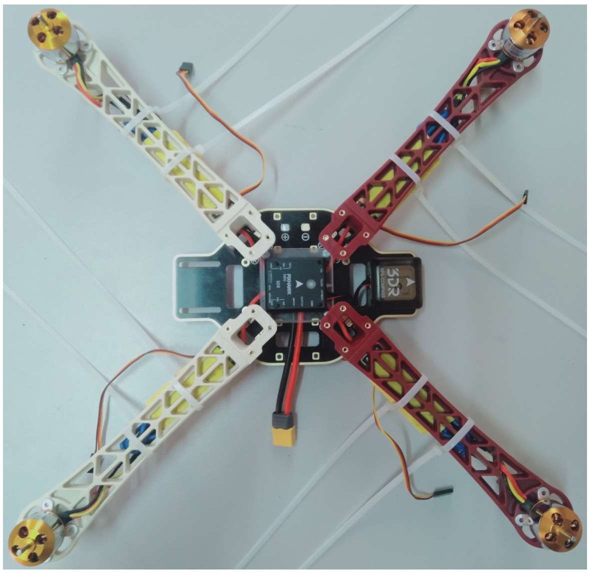


FIGURE 3.3: Mounting the motor's

- **Power Module mounting:** We begin by screwing the four arms to the main board, followed by the four output power modules. Following that, we solder the ESC power cables to each output in the correct order. After that, we cover all the soldered wires with UV green paint resin to isolate the outputs, ensuring the safety of all the components and preventing shorting or arcing.

- **Additional layer:** We improvised by constructing a middle floor made of Plexiglas to cover the lack of space on the main board, separating the power module, from the flight controller, for more efficiency, better aesthetics, and safety.

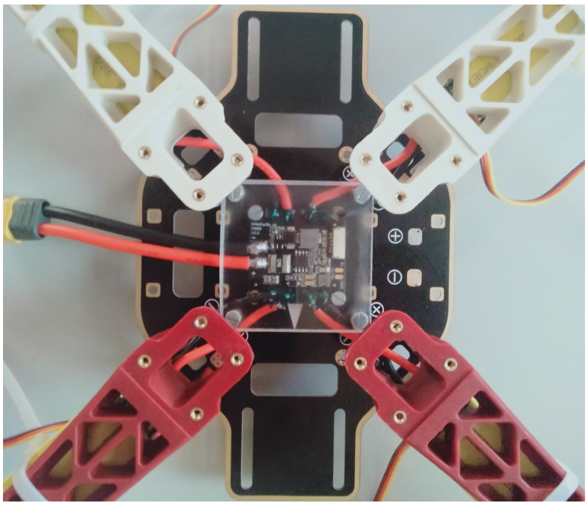


FIGURE 3.4: Middle floor

- **Mounting the flight controller:**

  The middle floor was screwed and fixed on top of the power module. Our PIXHAWK mini 3DR flight controller is positioned in front of our DJI f450 frame. Then, using foam mounting tape, we attach it on top of the new floor, directly at the structure's center of gravity.

- **Mounting the receiver and GPS module:**
  The quad rotor as a whole is going to be controlled using a turnigy 9X transmitter sending commands to our IA8 receiver mounted in the back of our main board. The IA8 can use either PWM passing thru 8 channels, and connecting each of them to our controller or in our case joining all the 8 channels in 1 named PPM. The servo connectors of each ESC goes to this 8 channel PWM connecting them to our flight controller at the end we orient our GPS compass to the front our UAV and we mount it after connecting it to our flight controller.

- **Flight controller wiring:**
  The receiver is connected to our PIXHAWK via the RCIN port and our 8-channel PWM breakout board via the MAIN/AUX output ports. The power module is then wired to a 6-pin connector that is responsible for power distribution. Finally, the switch, GPS and compass are linked to their appropriate ports.

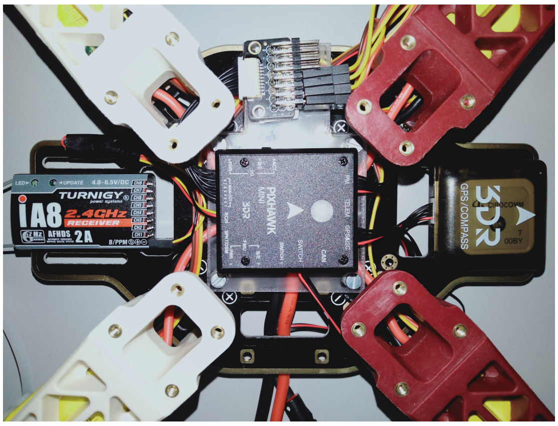


FIGURE 3.5: Electrical wiring

3.5 UAV configuration

In order to fine-tune the quad-rotor. Using the Turnigy BESC programming card, we began manually calibrating each ESC. Then we utilized the open-source QGroundControl software to properly configure our flight controller and evaluate the controls visually in real time. It also aids in the stabilization and control of our UAV in flight.

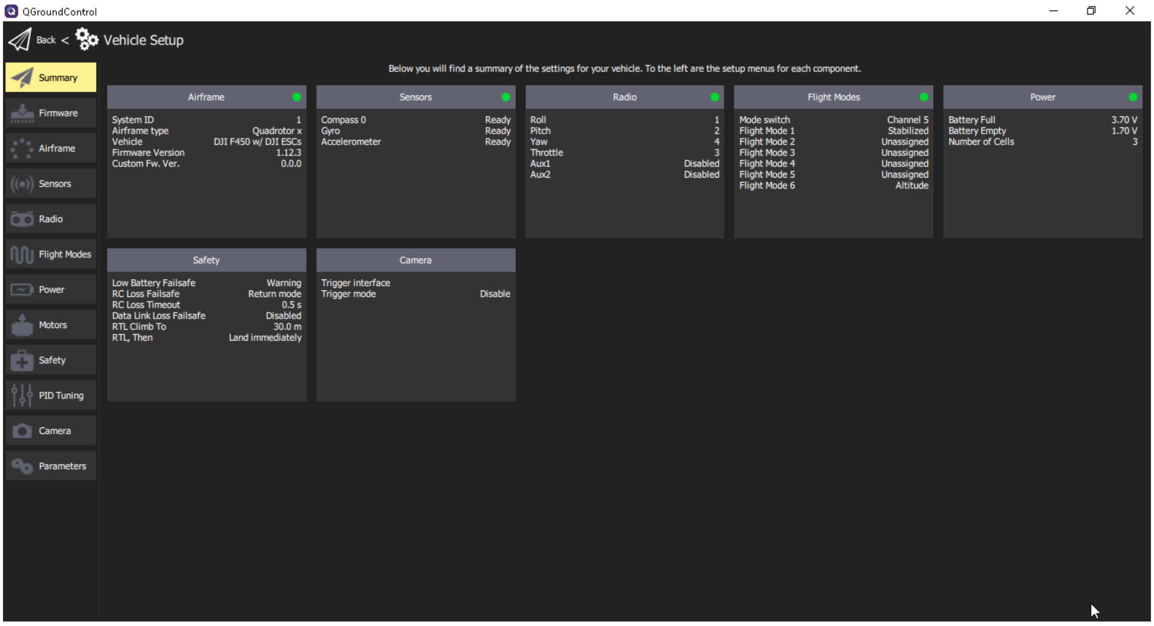


FIGURE 3.6: QGroundControl Summery

- **Firmware Upgrade:** We open QGroundControl after downloading and installing it, then go to vehicle setup, selecting firmware, and connect the flight controller to the computer through USB to start the firmware upgrade.

- **Airframe:** We choose the quad-rotor "X" form from a number of frame options, then the DJI f450 as our frame. After validating the frame selection, the flight controller will reboot automatically.

- **Sensors Balancing:** To balance our Flight controller, the pixhawk 3DR mini features gyroscope, compass, and accelerometer setup, so we calibrate each of them by imitating the movements and orientations given on the QGroundconrol interface.

- **Radio Transmitter calibration:** After setting up our Turnigy9X transmitter and selecting the appropriate mode. We calibrate our transmitter by replicating the joystick movement seen in QGroundControl and assigning it to a specified channel.

- **Flight Modes:** When we finish our transmitter calibration, we need to select our flight modes to switch from manual flights to assisted ones. after setting them in our QGroundControl all we need to do is to connect them with the transmitter the main used flight modes for quad-rotor are the following:

-In our case the flight modes we used are the following:

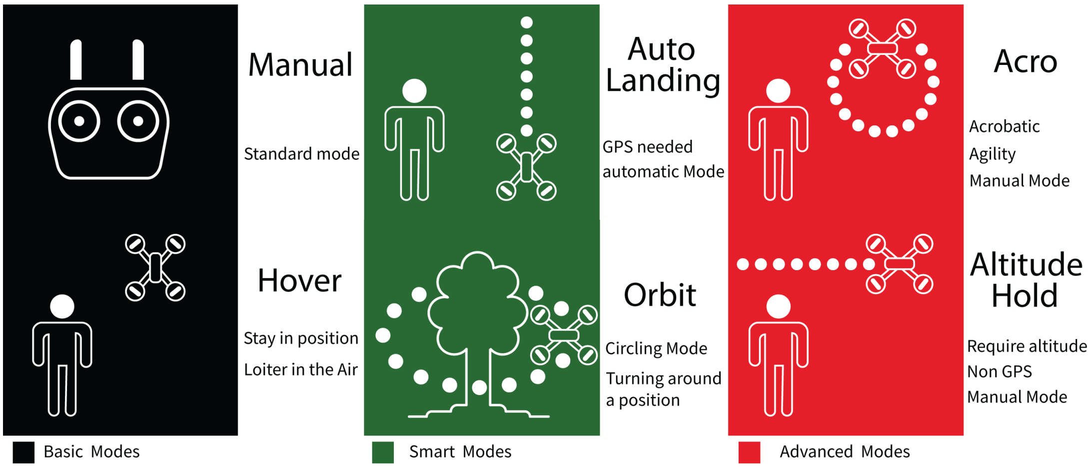


FIGURE 3.7: Quad-rotor flight modes

Loiter Mode: Position hold mode is similar to manual flying mode, except that when the sticks are released, the vehicle will decelerate to a stop and hold position for a more realistic feel.

Altitude Hold Mode: The Quad-Copter maintains a constant altitude while providing conventional control of roll, pitch, and yaw.

Stabilised Mode: Because of the more complicated controls, it is a more advanced mode than altitude hold or Loiter, allowing us to fly our vehicle manually while self-leveling the roll and pitch axes.

- **Power settings:** After we've configured the flight modes, we'll calibrate our ESCs and set our full and empty battery values based on the quantity of cells in the battery used.

- **Safety settings:** The last settings we need to change are the emergency settings in case of RC loss our drone will enter return mode to go back to its initial position and for the case of low battery the flight controller starts signaling.

3.6 Flight preparations

- We begin by validating the connection and charging the batteries to full capacity, then constructing a propeller protector to prevent the propellers from being damaged during the testing phase.

- The flight tests are performed in 3 main ways, assisted flight test using a UAV test bench to calibrate the Quad-copter. Then there's an indoor test with no exterior influences, followed by an outside test with external influences.

The outdoor test is more difficult since it is dependent on the atmospheric conditions in the region where the test will be conducted, as well as the weather and wind speed, which are the most important aspects in this test.

- After calibrating the drone, we must have a deep understanding of its movement and how it changes depending on the flight mode being used. Setting a kill-switch for emergency situations is also required, as is checking that the UAV pre-arming sequence is set and the arming switch is turned off before each flight.
- The environment of the flight, as the final pre-flight preparation, must adhere to a variety of criteria. To avoid any form of contact or impact, it's best to have a grassy open space with few trees or structures.
- After doing all the preparations for the flight, all that remains is to arm the drone shown in Figure 3.8 and take off.

Figure 3.8: Quad-Copter

3.7 Quadrotor PID Tuning

The pixhawk controller uses PID (proportional-integral-derivative) control which is a classic and most common method of controlling systems and quadrotors specifically. The main purpose of using a controller is to ensure the four performances: stability, speed, accuracy and overshoot of the system response.
The equation of the PID controller is:

$$u(t) = K_p(e(t) + \frac{1}{K_i}\int e(t)dt + K_d\frac{de(t)}{dt}) \quad (3.1)$$

The gain effects of PID are:

- K_p **proportional gain:** If the value of the gain K_p is greater than 1, it will improve the speed and accuracy of the closed-loop system. If it is less than 1, it acts as an attenuator, improving the stability of the system and reducing the overshoot in a closed loop, but the speed and accuracy are degraded.

- K_d **derivative gain:** It is used to eliminate overshoot, oscillations but it can heat up the motors.

- K_i **integral gain:** The integral action corrector is thus supposed to improve the precision of the servo system while all the other performances are decreased (speed, stability). It is necessary to choose its value well.

3.7.1 Quadrotor control architecture

According to the official documentation of the Px4, The PID controller's architecture consists of three cascaded controllers, with the primary controller's outputs feeding into the second controller's inputs.

The controllers are a mix between PID and PI controllers. They control the position, velocity, acceleration, as well as its attitude and angular velocity outputs. The outermost control loop is a position controller, whereas the inner loops are much faster.

The cascaded control architecture is shown in Figure 3.9:

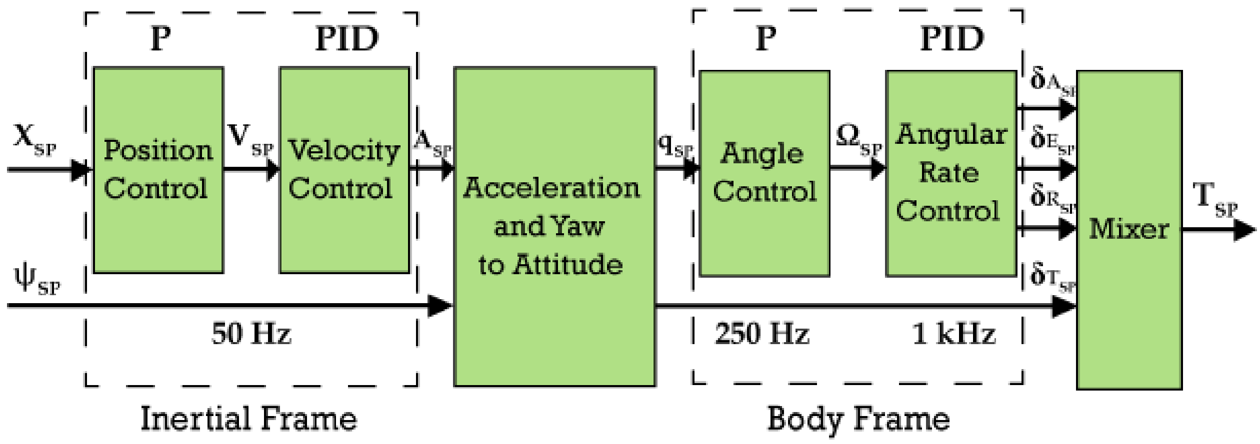


FIGURE 3.9: Cascaded control architecture

The angular rate controller

The integral action is limited to avoid wind-up, and the derivative path is filtered with a low-pass filter (LPF) to reduce noise. The outputs of the loop are also limited in the mixer, typically to -1 and 1.

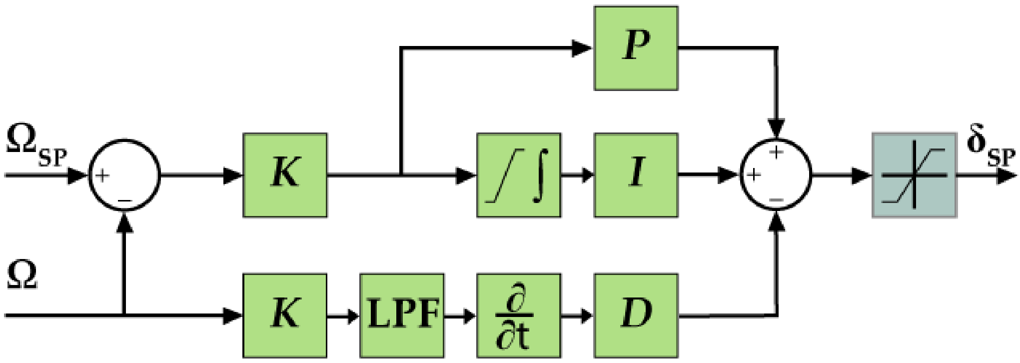


FIGURE 3.10: Angular rate controller loop

The attitude controller

An attitude controller based on the unit quaternion approach is used to develop a feedback rule that assures stability and robustness of the quadrocopter in any desired physical orientation.

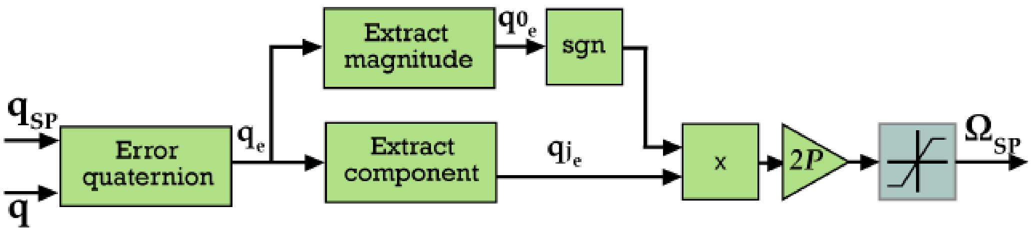


FIGURE 3.11: Attitude controller loop

The velocity controller

To stabilize velocity commands and acceleration, a PID controller is employed. The integrator uses a clamping technique to implement an anti-reset windup (ARW). In ordre to keep the commanded acceleration saturated, a saturation block is used.

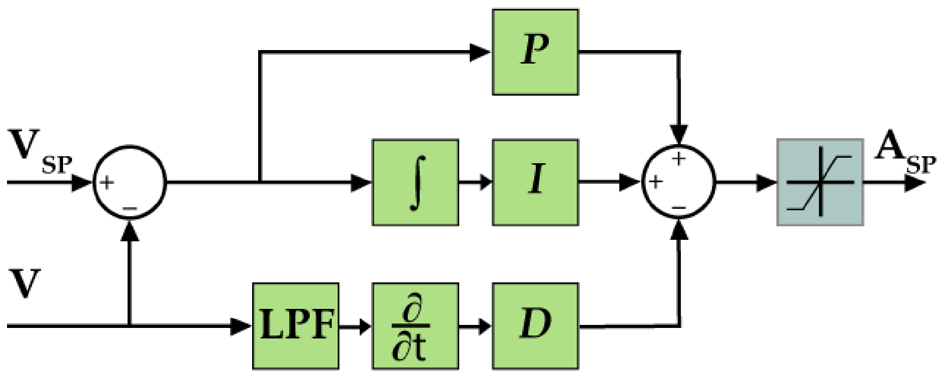


FIGURE 3.12: Velocity controller loop

The position Controller

It uses only P action to command velocity. To keep the velocity within certain limitations, the commanded velocity is saturated.

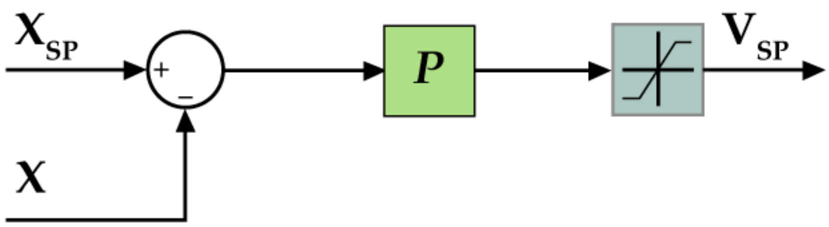


FIGURE 3.13: Position controller loop

3.7.2 PID tuning procedure

The QGroundControl PID Tuning setup displays the vehicle set-point and response curves in real time. The purpose of tuning is to set the P/I/D values so that the Response curve closely resembles the setpoint curve (i.e. a fast response without overshoots).
In the latest version of QGroundControl, only the Rate controller tuning parameters are adjusted, because they are the most important. If the tuning is good, the other controllers often need no or only minor adjustments. That's why we have access to adjust only the inner controller.
Figures 3.14, 3.16, and 3.15 show the response and the setpoint curve of each movement after tuning procedure.

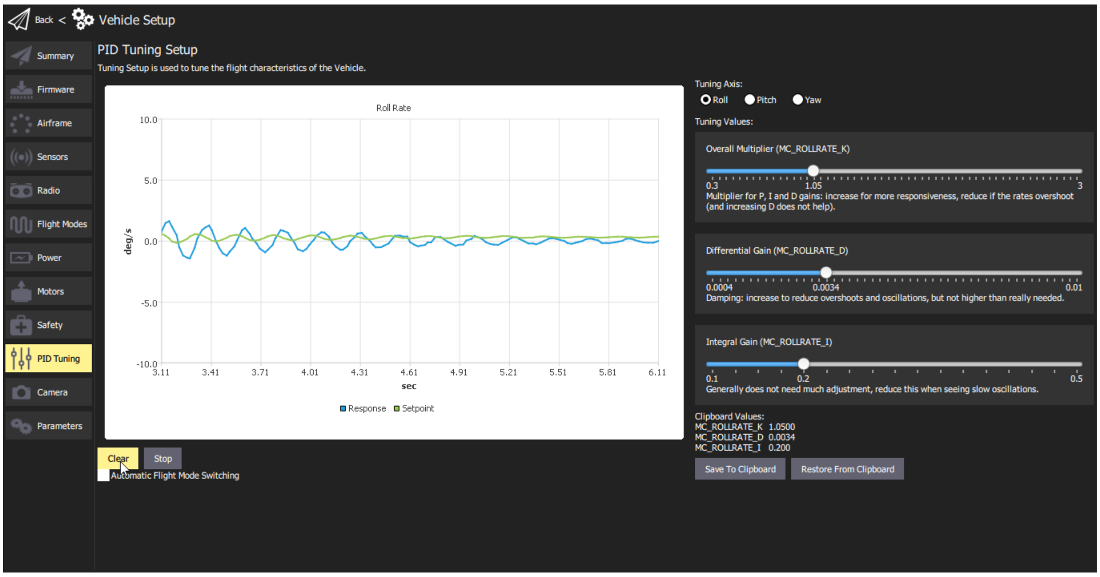


FIGURE 3.14: Roll rate response and setpoint

Each controller's parameters are adjusted by making a very quick change by moving the drone. Therefore, we adjust the values so that the response follows the setpoint. We notice that we have oscillations and a static error in the response of the system. It is adjusted by modifying the proportional and integral gains.

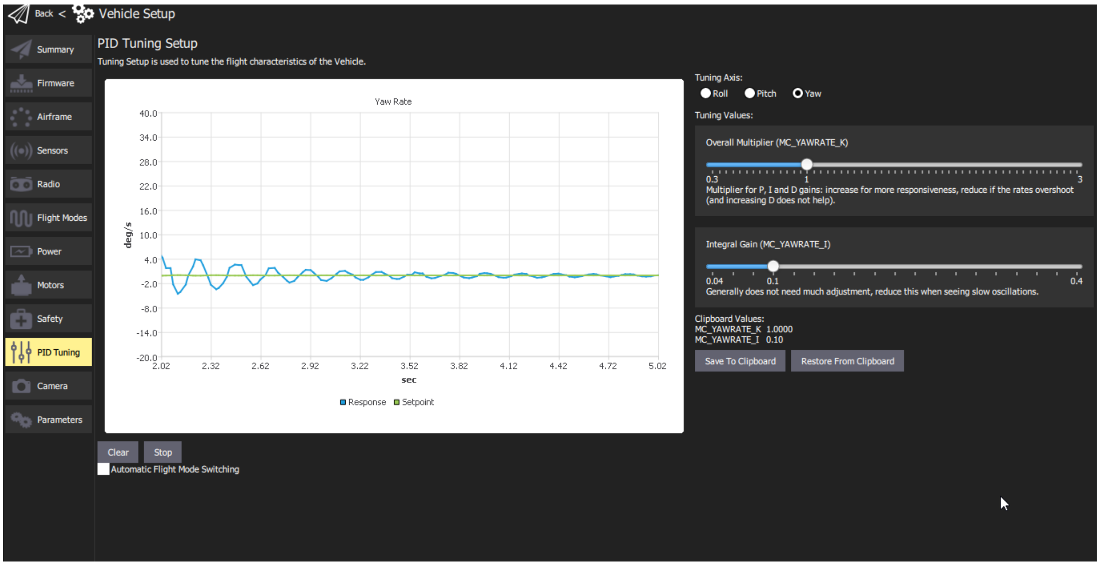


FIGURE 3.15: Yaw rate response and setpoint

In the response of the yaw motion, we can see that we have a small static error and small oscillations and their amplitudes decrease with time. We solve this problem by decreasing the value of the proportional and integral gains

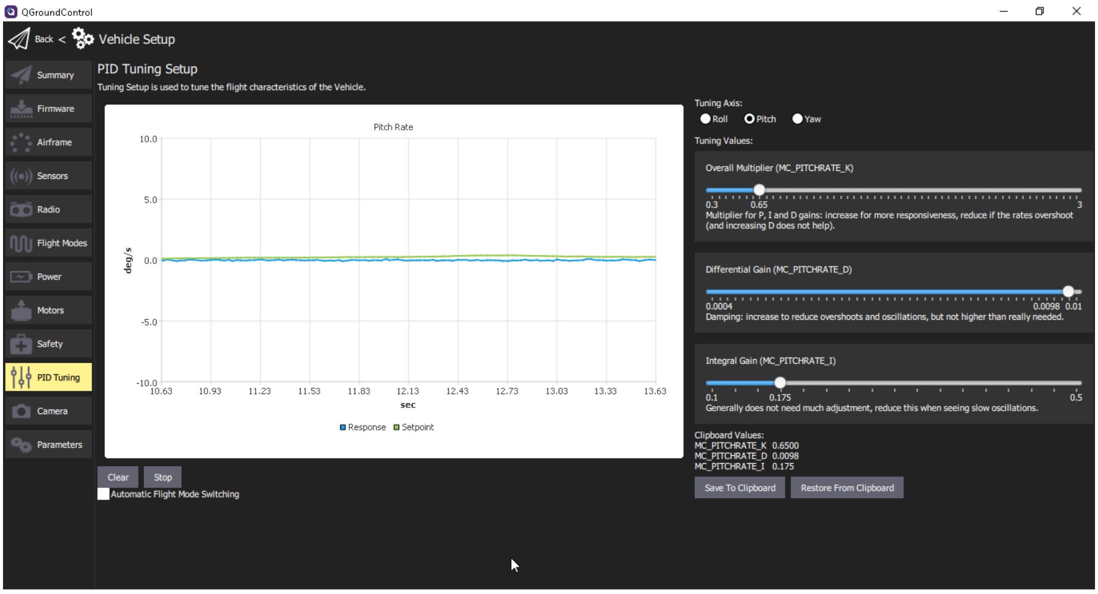


FIGURE 3.16: Pitch response and setpoint

In the response to the height, we can observe that the system stabilizes quickly and the error is low. Therefore, the parameter values of the controller do not need to be changed.

The values of the gains of all the controllers are summarized in table 3.1.

motion	Kp	Ki	Kd
yaw	1	0.1	-
roll	1	0.2	0.034
yaw	0.65	0.0098	0.175

TABLE 3.1: Controller's gains

3.8 Conclusion

In Chapter three, we have discussed the process of assembling a quadrotor UAV, starting with the assembly of the mechanical structure, then installing the electronic components, finally explaining the different steps of configuring, calibrating and controlling the UAV using the QGroundControl software.

CHAPTER

4

DESIGN OF AIR QUALITY MONITORING SYSTEM

4.1 Introduction

After assembling and configuring the drone, the next step is to design an air quality monitoring system that allows for real-time data transfer from the sensors while the drone is in flight, as well as receiving data via the gateway to estimate air quality and show the result on the server interface. This chapter will first discuss the structure and working principles of each stage of the system, followed by a list of the various electronic components and circuits used. Air quality estimation using fuzzy logic is explained at the end of this chapter.

4.2 Presentation of air quality monitoring system

The air quality monitoring system is made up of three parts: a transmission part where we will collect data from sensors such as air quality sensors and temperature sensors and send it to the receiver station using radio communication modules. Then, the data reception part consists of receive data from the transmitter module and transfers it to a server or the cloud through Wi-Fi. Finally, the last part of the system is the analysis of this data by estimating the air quality index by two approaches which are the conventional approach and fuzzy logic and display the results on Thingspeak server. Figure 4.2 describes the architecture of the system.

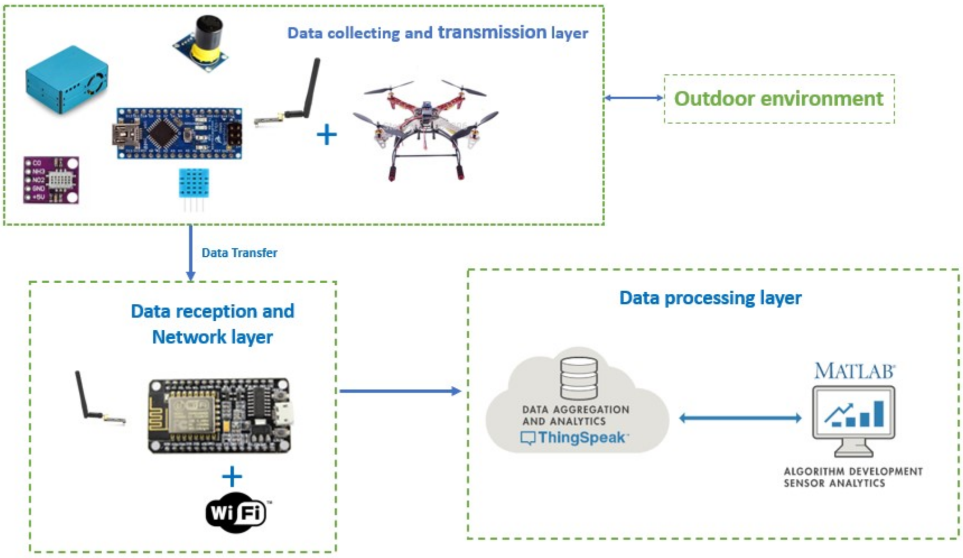


FIGURE 4.1: System architecture

The major actions of the processing system are depicted in the flowchart below. First, a microcontroller is used to calibrate and read the data sensors, which are then sent to the receiving station via radio modules. Then, another microcontroller uses Wi-Fi to send the data to the Thing Talk server, which allows seeing their traces. The last step is to calculate the air quality index using two approaches.

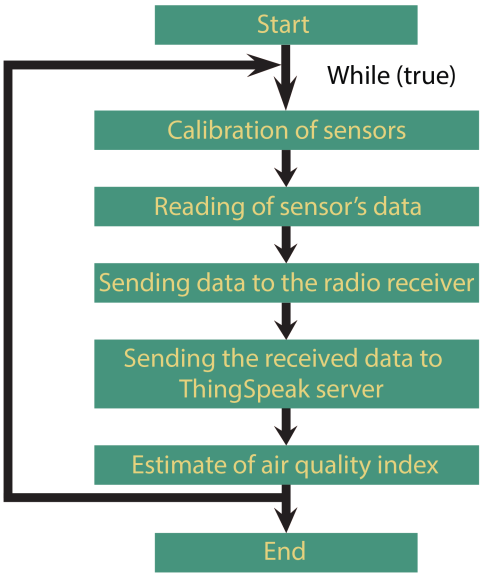


FIGURE 4.2: Data processing flow chart

4.3 Transmission layer

In this part, we calibrate the several sensors for the acquisition of their measurements as the drone flies, and then transmit them to the Gateway using RF modules. Figure 4.3 shows Block diagram of the data collection hardware. the transmission system is made up of a sensor block with multiple pollutant sensors, a central processing unit for data collecting and processing, a power supply block, and a GPS to determine the area's location. A radio frequency (RF) unit is being used to transmit the measurements.

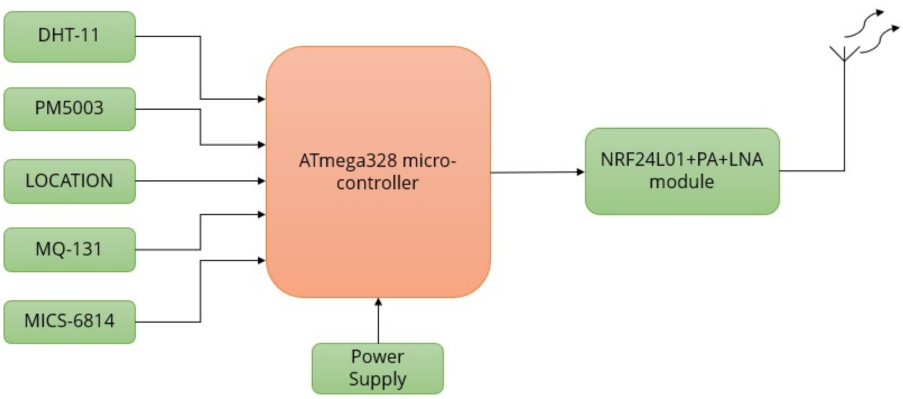


FIGURE 4.3: Block diagram of the data collection hardware

4.3.1 Components used

Arduino Nano

Based on the ATmega328 microcontroller, the Arduino Nano is a lightweight, comprehensive, and breadboard-friendly board (Arduino Nano 3. x). It offers a lot of the same features as the Arduino Duemilanove, but it comes in different packaging. It just has a DC power jack and uses a Mini-B USB cable rather than a conventional one. It only weighs 7g, making it ideal for our UAV's payload. Power consumption, availability of software and hardware development tools, product availability, reliability, documentation, and cost effectiveness are all factors in the decision to select this microcontroller.

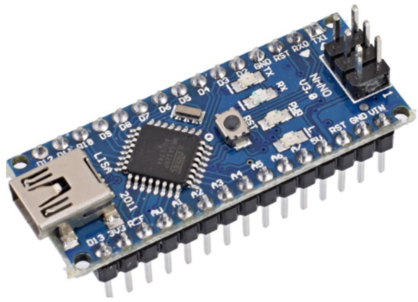


Figure 4.4: Arduino Nano

Table 4.1 summarizes the main features of ATmega328 microcontroller.

Features	Value
CPU type	8-bit AVR
Maximum CPU speed	1MHz to 20MHz
Flash memory	32Kb
SRAM	2Kb
EEPROM	1Kb
Maximum I/O pins	23GPIO

Table 4.1: ATmega328 microcontroller features

Sensors

1. **MICS-6814**:

   The MiCS-6814 is a three-sensor device that can be used to detect gas leaks and monitor outdoor air quality. The MiCS-6814 can detect a wide range of harmful gases and can measure three gases (Co, NH3 and NO2) at once due to its multi channels, it can assist in monitoring gas concentrations in situations when more than one gas is expected.

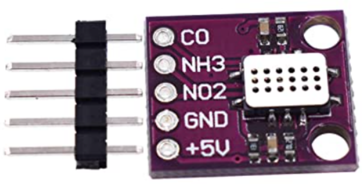


Figure 4.5: MICS-6814 Gas Sensor Module

2. **PMS5003 Air Quality Sensor**:

   The PMS5003 is a digital and universal particle concentration sensor that may be used to determine the number of suspended particles in the air, and particle concentration, and output the data in a digital format. This sensor can be used in a variety of instruments that measure suspended particle concentrations in the air or other environmental improvement equipment to deliver accurate concentration data in real time. Its characteristics: are stability, real-time and continuous dust detection, and ease of use. Noise levels are low, and power usage is quite low.

FIGURE 4.6: PMS5003 Air Quality Sensor

Table 4.2 summarises its technical features

Detection range	0.3-1.0 ,1.0-2.5,2.5-10
Standard Volume	0.1 (L)
Total Response Time	$\leq$ %10(s)%
Tem. Humidity	-10-60°C, 0-99
Standard test circuit	Min:4.5 Max: 5 (V)

TABLE 4.2: PM5003 technical characteristics

This sort of sensor works on the principle of laser scattering, which entails producing scattering by irradiating particles in the air with a laser, collecting the scattering light to a certain amount, and lastly obtaining the scattering light change curve over time. Then, a microprocessor can determine the equivalent diameter of particles and the number of particles of various diameters per unit volume.

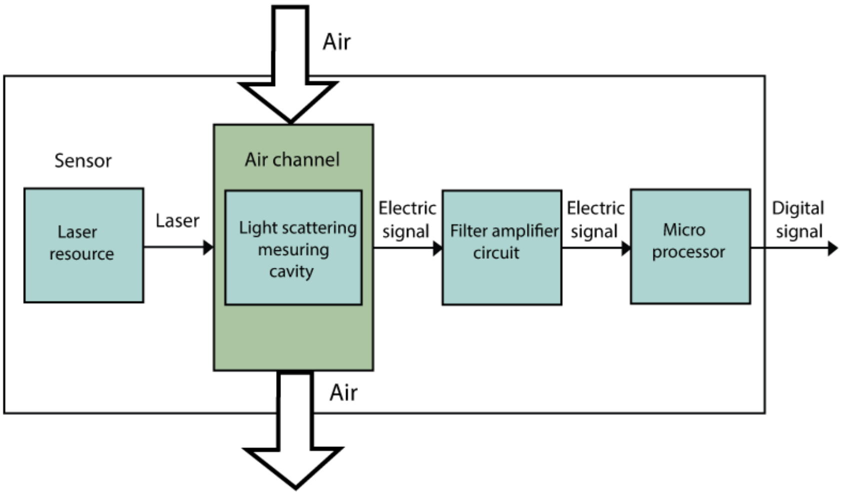


FIGURE 4.7: Working principle of PMS5003

3. **MQ131 Ozone Sensor**:

   The MQ-131 ozone gas sensor detects ozone levels in the atmosphere. It offers a wide range of ozone sensitivity and benefits such as long lifespan, low cost, and a simple drive circuit, among others. A sensor's internal preheater aids in achieving optimal sensing conditions. The sensor, however, requires additional current due to the inbuilt preheater. Fortunately, the sensor is pre-calibrated; nonetheless, for precise results, final calibration is required.

FIGURE 4.8: MQ131 Ozone Sensor

   Table 4.3l ists its main technical characteristics:

4. **DHT11–temperature and humidity sensor**:

   The DHT11 is a temperature and humidity sensor that is widely used. The sensor includes a dedicated NTC for temperature measurement and an 8-bit microprocessor for serial data output of temperature and humidity values. The sensor is factory calibrated, making it simple to connect to other microcontrollers. With an accuracy of 1°C and 1 percent, the sensor can measure temperature from 0°C to 50°C and humidity from 20 % to 90 %.

Sensor Type	Semiconductor
Detection range	10-1000 ppb Ozone
Heater Voltage	5.0V±0.1V AC or DC
Sensitivity	Rs(in 200ppb O3 Rs(in air)≥2
Load Resistance	Adjustable
Tem. Humidity	20 2 55% ± 5%RH
Standard test circuit	Vc:5.0V±0.1V

Table 4.3: MQ131 technical characteristics

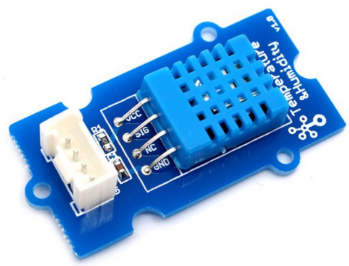


Figure 4.9: DHT11–temperature and humidity sensor

NRF24L01+PA+LNA Wireless transceiver Module

In order to transmit sensor measurements, we use the NRF24L01+PA+LNA module which is a small transceiver module that allows communication between several Arduino boards wirelessly and remotely with the RF protocol. Through this function, it is used in numerous applications, such as remote monitoring of sensor data, robot control. It is designed to operate in the global ISM frequency of 2.4 GHz and can be composed of star network.

This module communicates via a 4-pin serial peripheral interface (SPI) with a maximum data rate of 10 Mbps. The interface configures parameters such as frequency channel, output power, and data rate from 250kbps to 2Mbps.

It has a SMA connector, a duck antenna, and a special RFX2401C chip with a PA power amplifier, an LNA low noise amplifier, and a transmit-receive switching circuit. With a data rate of 1 Mbps, this module has a transmission range of about 720 meters.

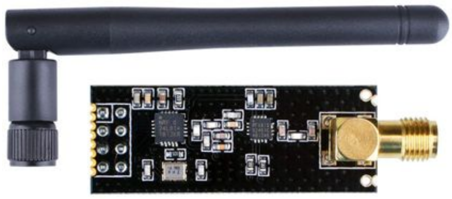


FIGURE 4.10: NRF24L01+PA+LNA Wireless Module

4.4 Data reception layer

In the reception part, we connect the NRF24L01 transceiver module, which is also known as the Gateway with the NodeMCU ESP8266 development to receive the data collected.

NodeMCU ESP8266

The NodeMCU (Node MicroController Unit) is an open-source software and hardware development environment based on the ESP8266, a low-cost System-on-a-Chip. It includes all of the essential components of a computer, including the processor, memory, networking (Wi-Fi), and even a contemporary operating system and SDK. As a result, it's a great fit for a variety of Internet of Things (IoT) projects.

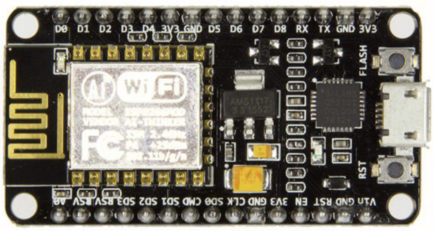


FIGURE 4.11: NodeMCU ESP8266

4.4.1 Receiver circuit Diagram

Figure 4.12 represents the connection of the NRF24L01 pins with the NodeMCU ESP8266 board. The Gateway can connect to the WiFi network. It uses the NRF24L01 transceiver module to receive data wirelessly. The values will then be uploaded to Thingspeak Server.

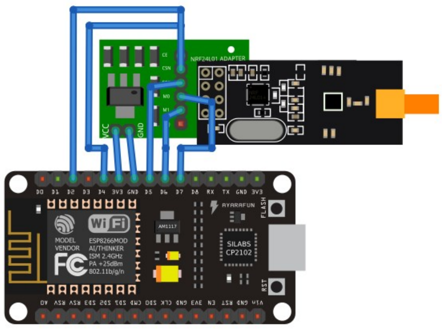


FIGURE 4.12: Receiver Circuit diagram

4.4.2 Internet of Things (IoT)

The Internet of Things (IoT) is a new trend that involves connecting a huge number of embedded devices (things) to the Internet. These connected gadgets exchange data with people and other devices, and they frequently send sensor data to cloud storage and cloud computing resources, where it is processed and analyzed for valuable insights. This trend is being aided by low-cost cloud computing capacity and greater device connectivity [32].

IoT solutions are used in various applications such as environmental monitoring and control, health and industrial monitoring and control. Figure 4.13 describes the major components of internet of things.

FIGURE 4.13: Major components of Internet of Things

4.4.3 ThingSpeak cloud platform

ThingSpeak™ is a IoT cloud analytics platform from MathWorks®, based on open source information that allows users to aggregate, visualize and analyze live data streams. It uses HTTP protocol to store and retrieve data from the sensors [33].

It provides real-time visualizations of data sent to it from various devices. Thanks to the ability to execute MATLAB® code in ThingSpeak, it can analyze and process data as it arrives in real time [34]. ThingSpeak Cloud is often used for prototypes and proofs of concept of IoT systems that require analysis.

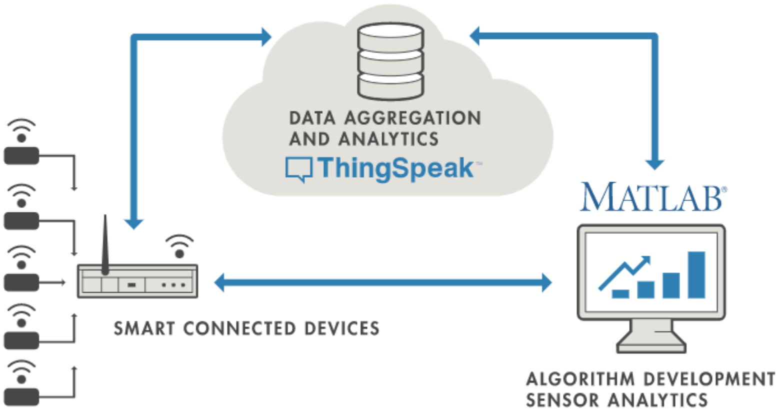


FIGURE 4.14: Layout of ThingSpeak server for IoT

4.5 Estimation of air quality Index

The last step of our system consists in estimating the air quality index and its category using the conventional and fuzzy logic approaches. The calculations for the air quality index and its categories are detailed in the sections follows. The conventional technique calculates the AQI using Linear Interpolation, however the fuzzy logic method employs fuzzification functions to get the quality index.

4.5.1 Conventional approach for calculating AQI

The conventional method uses linear interpolation to calculate the AQI. It takes the highest value calculated for each pollutant listed in the first chapter according to the EPA method by identifying the pollutant concentrations from Table 4.6 and calculating the air quality index value using equation (1.1) and round it to the nearest integer. We create a MATLAB script On MATLAB analysis application In Thingspeak server that contains all this procedure to obtain results in real time.

For example, suppose that we have an 8-hour ozone value of 0.082 ppm, a PM2.5 value of 45 µg/m3, and a CO value of 5 ppm. We apply the equation 3-times.

$IQ_{O3} = \frac{(150-101)*(0.082-0.071)}{(0.085-0.071)} + 101 = 140.$

$IQ_{PM} = \frac{(150-101)*(45-35.5)}{(55.4-35.5)} + 101 = 124.$

$IQ_{CO} = \frac{(100-51)*(5-4.5)}{(9.4-4.5)} + 51 = 56.$

The AQI is 140, with ozone as the responsible pollutant.

4.5.2 Fuzzy approach for calculating AQI

The fuzzy logic approach to estimating the air quality index requires the creation of a fuzzy logic system that has the pollutant concentrations as inputs, and its output is the air quality index. The MATLAB fuzzy logic toolbox is not supported by ThingSpeak, which means that the data from the server must be passed to the MATLAB Desktop for data analysis. After processing the data, we send it to the server.

Fuzzy logic

Fuzzy logic is a concept introduced by Lotfi Zadeh of the University of California, based on "degrees of truth" rather than the usual "true or false" (1 or 0) Boolean logic that the modern computer is built on [35]. It does not necessitate any quantitative models, resulting in faster and simpler programming as well as greater control over the system's stability, reliability, efficiency, and longevity. Figure 4.18 shows the structure of fuzzy logic system.

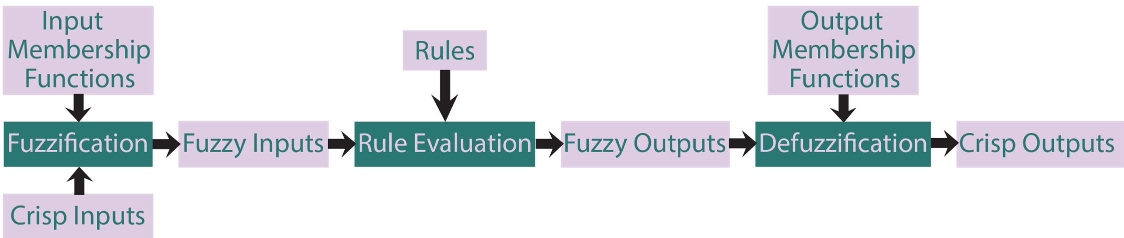


FIGURE 4.15: Fuzzy logic system structure

MATLAB Fuzzy Logic Toolbox

The Fuzzy Logic Toolbox is a tool for creating and editing fuzzy inference systems. Employing graphical tools or command-line functions, or applying clustering or adaptive neuro-fuzzy algorithms to generate them automatically [36].

Steps of fuzzy logic process

1. **Defining the input variables** we have four pollutants as inputs to calculate the final air quality index.

O3 (1 hour (ppm))	
Breakpoints	Category
-	Good
-	Moderate
0.125-0.164	Unhealthy for sensitive groups
0.165-0.204	Unhealthy
0.205-0.404	Very-Unhealthy
0.405-0.604	Hazardous

(A) O3 breakpoints values

CO (8 hour (ppm))	
Index	Category
0-4.4	Good
4.5-9.4	Moderate
9.5-12.4	Unhealthy for sensitive groups
12.5-15.4	Unhealthy
15.5-30.4	Very-Unhealthy
30.5-50.4	Hazardous

(B) CO breakpoints values

PM 2.5 (ug/m^3)	
Breakpoints	Category
0-12	Good
12.1-35.4	Moderate
35.5-55.4	Unhealthy for sensitive groups
55.5-150.4	Unhealthy
150.5-250.4	Very-Unhealthy
250.5-500.4	Hazardous

(A) PM2.5 breakpoints values

PM 10 (ug/m^3)	
Breakpoints	Category
0-54	Good
54-154	Moderate
155-254	Unhealthy for sensitive groups
255-354	Unhealthy
355-424	Very-Unhealthy
425-604	Hazardous

(B) PM10 breakpoints values

NO2(ppb)	
Breakpoints	Category
0-53	Good
53-100	Moderate
101-360	Unhealthy for sensitive groups
361-649	Unhealthy
650-1249	Very-Unhealthy
1250-2049	Hazardous

Table 4.6: Breakpoints values for pollutants

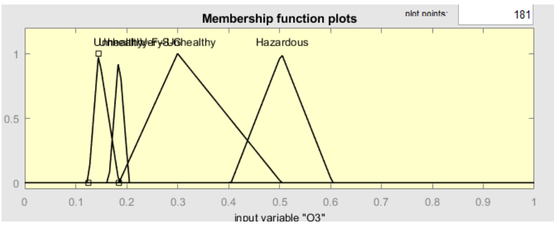
AQI	
Breakpoints	Category
0-50	Good
51-100	Moderate
101-150	Unhealthy for sensitive groups
151-200	Unhealthy
201-300	Very-Unhealthy
301-500	Hazardous

TABLE 4.7: Fuzzy logic system output

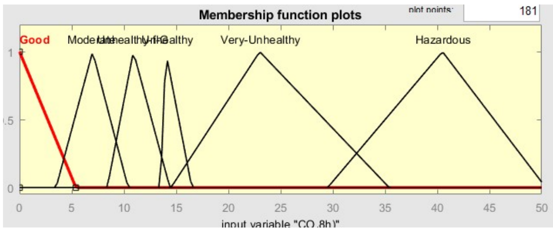
2. **Fuzzification**

In this step, we convert The crisp values into membership grades for linguistic terms of fuzzy sets. Each linguistic phrase is assigned a grade using the membership function [37].In our fuzzy inference system (FIS), the triangle MF were chosen because they are the most commonly found in practice; they are constructed using straight lines, making them straightforward to utilize [38] [39].

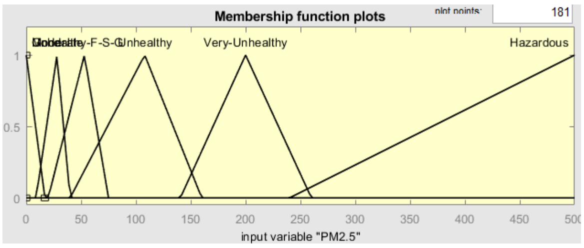
For each input and output variable in our FIS model we use seven linguistic variables and we define the following and membership functions. Figure 4.16 describes the plots of membership function used.



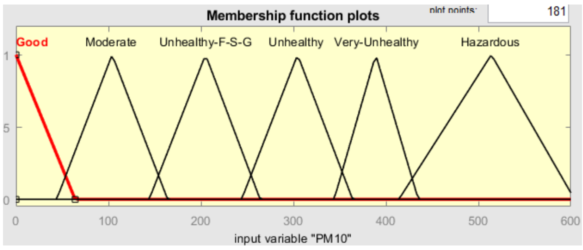
(A) Membership function plots for O3



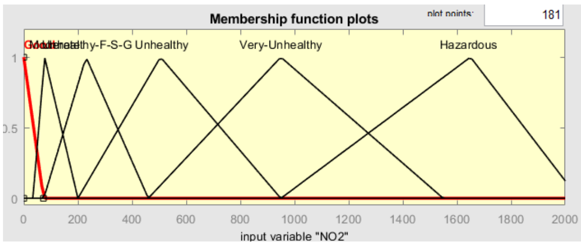
(B) Membership function plots for CO



(C) Membership function plots for PM2.5



(D) Membership function plots for PM10



(E) Membership function plots for NO2

FIGURE 4.16: Membership function pollutants

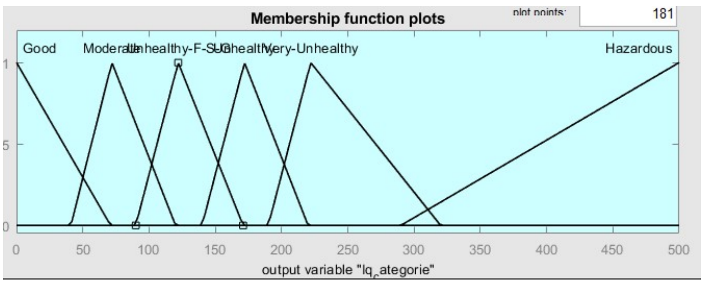


FIGURE 4.17: Output membership function

3. **Fuzzy inference rules:** In this step, we define the rules generally IF-Then conditions that regulate and perform the decision making in the fuzzy logic system.

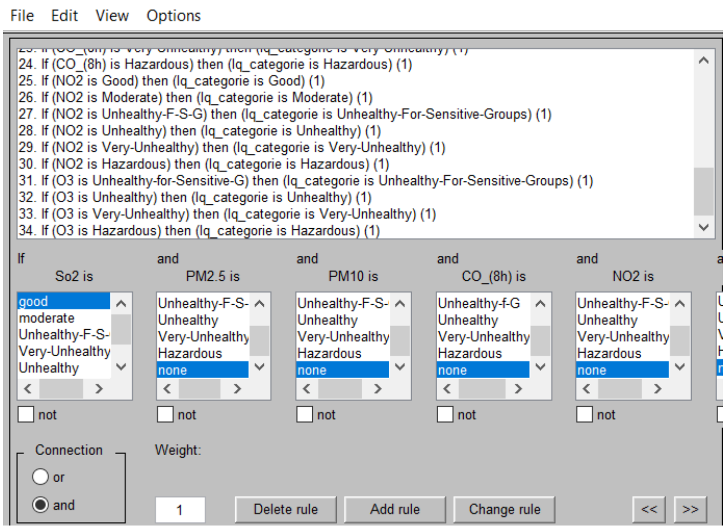


FIGURE 4.18: Fuzzy inference rule system

4. **Defuzzification:** The final step in the fuzzy logic process is to convert the fuzzy output to crisp output using the center of gravity method, which is a common method of defuzzification. Figure 4.19 describes the the whole system as a block diagram.

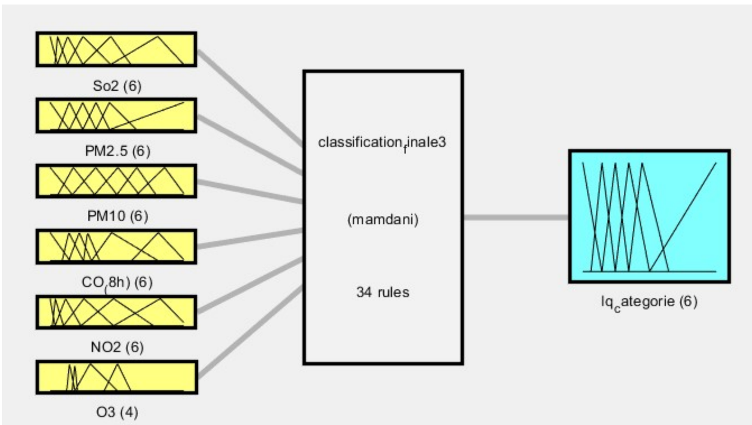


FIGURE 4.19: **Block diagram of fuzzy system**

4.6 Conclusion

The implementation of the air quality monitoring system is covered in this chapter, beginning with a description of the components utilized and the electronic circuit of the transmitter and receiver gateway. Next, we explained the process of transmitting data from the sensor node to the gateway via Thingspeak on the Cloud. Finally, we processed this data by two methods, the classical method and the fuzzy logic approach by explaining the different steps of them. To evaluate the performance of the system, experimental tests are required.

CHAPTER

5

AIR QUALITY MONITORING UAV RESULTS

5.1 Introduction

After going over the many steps of drone assembly and the realization of the payload, which is an air quality monitoring device, Experiments and flying tests are being done to evaluate the quad-copter's flight performance and to measure air quality in various locations throughout Tlemcen city.

5.2 Presentation of drone

At the end of our assembly all that is left is to set up our propellers respecting the motors designated spinning directions and then mounting our drone on our landing gear for smoother take off and lading but lastly we fix our propellers protection for additional safety and to avoid damaging the propellers in case of crash, the finalised product is shown in Figure 5.1:

FIGURE 5.1: Quad-copter

5.3 Presentation of flying tests

The flight test is separated in three main fazes starting from the most simple execution by assisting our quad-copter by fixing it on a three degree of freedom (DOF) test bench using it to calibrate and test the capabilities of our drone to execute with constancy the commands sent from our controller. The last remaining axis would be the throttle controlling vertical position, leading us to start the second faze the indoor test flight.

In the indoor test flight, we give full freedom to our drone in an enclosed surface and try to test the stability of the flight. which means the consistency of controls execution and the length of our flight period.

Finally and most importantly problem troubleshooting, were we correct all the errors and fix all the residuals and details from the last practice tests. This faze has the most important role in the quad-copter flight tests, but its effectiveness can only be approved if its applicable outdoor in an environment where all the degrees of freedom of the drone are released and affected.

The exterior factors are also being applied on the UAV mainly the wind causing it to shift positions and forcing it to correct and adjust to the new position or entirely counter the wind to stay in the same location the different flight tests are shown in Figure 5.2.

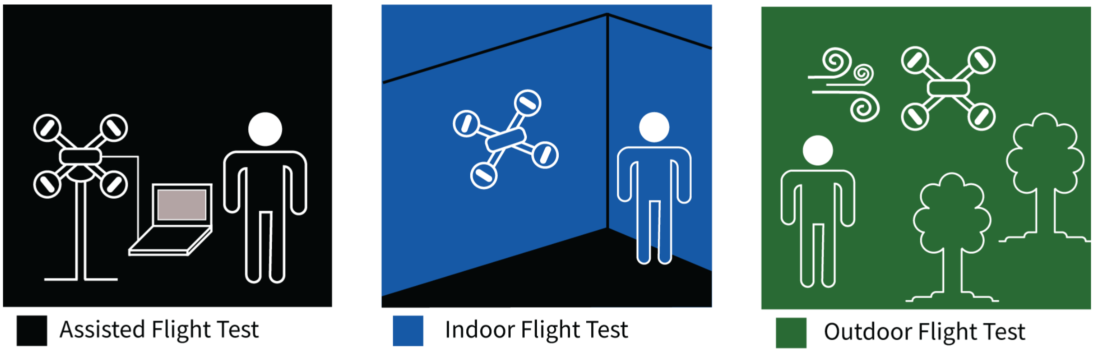


FIGURE 5.2: Different flight tests

Before doing any of these mentioned tests we need to start by verifying a number pre-flight prevention :

- Checking if the battery is fully charged because the drone will be malfunctioning and affecting our tests negatively or even worse shutting down mid flight.
- Doing a quick recheck of the motors order if we respected the numbers shown on the air-frame used by the configuration softaware QGroundControl (QGC).
- Monting the propellers on each motor respecting the spinning direction of the motors, because for clock wise spinning motors there is a designated form of propellers going from the trailing edge (or lower edge) of a propeller to the leading edge (or higher edge) following the direction of the rotation of the motor clock wise (CK) or counter clock wise (CCK) all this to avoid the propellers from pushing the air upwards causing the drone to drop down instead of lifting up by pushing the air downwards.
- lastly, checking if the kill switch is set from QGC to our transmitter to give us the ability to force shutdown if a problem occurs in the landing or arming but to be avoided mid flight after take-off.

After checking all the conditions only then we can start our flight test :

5.3.1 Assisted flight test

This is the first flight test, and the purpose is to see how the drone reacts to directions from our transmitter. To make this test bench, we'll need to create a support consisting of a ball joint installed on a metal post that's attached to the ground. In our situation, we fixed our quadcopter on a metal plate after mounting it on a static desk. Then we screwed it onto the ball joint, allowing our drone to move freely on the pitch, roll, and yaw axes while keeping the altitude in a single vertical position, as shown in Figure 5.3.

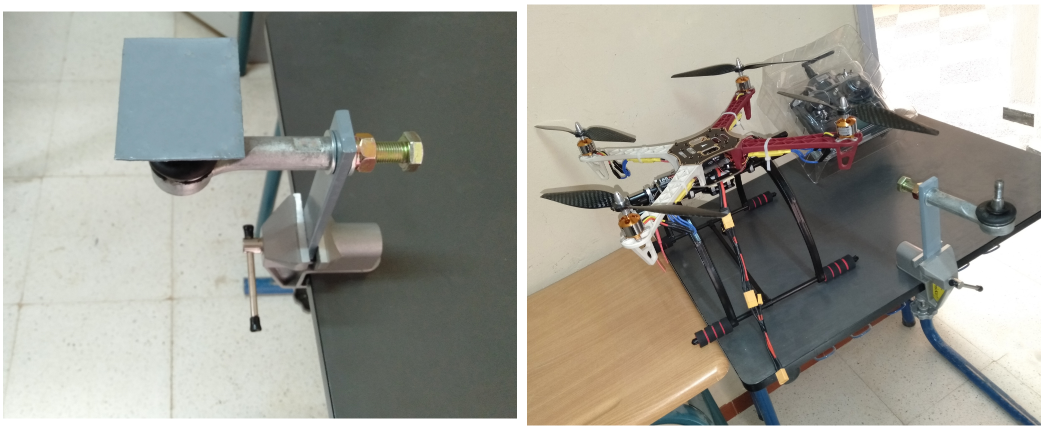


FIGURE 5.3: Test bench

All that is left is to connect the battery to our power module and start our series of tests and trimming our results accordingly to our desired stability and movement precision by executing small movements and seeing the results accordingly.
We began by testing a few pitch movements from forward to backwards and noting the time of response, then repeating the process for yaw and roll, and if the resulting movements are too sudden or too large. We switch from testing to trimming by using the controls and adding a sub-trim margin to each of them until we reach a consistent execution of each and every movement. The test bench and quad-copter setup is shown in the Figure bellow.

FIGURE 5.4: Assisted flight tests

5.3.2 Indoor flight test

After completing the primary flight test, we place our UAV in an enclosed room with no external factors, then we set our quad-copter on the ground and begin our flight tests. However, for the safety of our drone, we created four supports and placed each one on the end point of every single wooden arm, which will affect our drone's ability to lift up, but they will serve as a safety measures to avoid damaging the propellers and the entirety of our quad-copter, and as extensions for the arm making them the first point of contact with the ground, in case of crashing. Figure 5.5 shows our UAV with the supports mounted on each arm.

FIGURE 5.5: UAV flight crash support

We begin by plugging the battery, arming the drone and throttling until it takes off, as opposed to the assisted test flight, in which we grant all four degrees of freedom, including the throttle, which affects vertical position and granting it a mobile position, and then we continue to test the response of our UAV to each command sent from our transmitter, and we correct any abnormalities by correcting them similarly to the assisted test flight to try and get as close as possible to the desired stability of our quad-copter.

FIGURE 5.6: Indoor test

5.3.3 Outdoor flight test

Figure 5.7 was taken from the last flight test and the most relevant. Our study's purpose is to develop an air quality monitoring system, which means that the AQM device that will be utilized in the field will be influenced by a variety of factors, most notably the measurement time and wind. As a result, the stability of the response under these conditions will be used to evaluate our system's performance. The results have become more near to success as the tests have been repeated.

FIGURE 5.7: Outdoor test

5.3.4 Observations and discussion

In our test sequence, we noticed a margin of drift in the take-off consisting of a combination of yaw, which causes our drone to spin clockwise, and a slight roll and pitch movement to its front left side, creating an inconsistent flaying test. The standard solution to correct all of these movements causing instability in our flight is to use the trimming tool in QGroundControl, by creating opposite motion of the undesirable take-off movement so they cancel each other causing the quad-copter to not drift again or at least to minimise the intensity of that movement.

When correcting our drifting issue, we encountered another problem. Our drone's landing speed was excessively fast and sudden, causing damage to the landing gear and even the internal structure of the quadcopter. To avoid this, we increased the minimum throttle power, which allowed the drone to take off faster and continue lifting and dropping the quadcopter in a smoother and less aggressive manner by lowering the throttle speed of the motors.

After a number of flight tests, we noticed that our quadcopter trimming was inefficient and the drifting mid-flight tests made us uncertain about the cause of drifting being either bad trimming or failing motors due to lack of regulation of the power provided from the power module.

In the end, we tried multiple outdoor tests, and we observed that our UAV can go to bigger heights, but the landing was still not smooth.

5.4 Presentation of air quality monitoring device

The completed electronic included in the UAV is shown Figure 5.8. To protect the various components from external disturbance, we used a plastic box made by 3D printer.

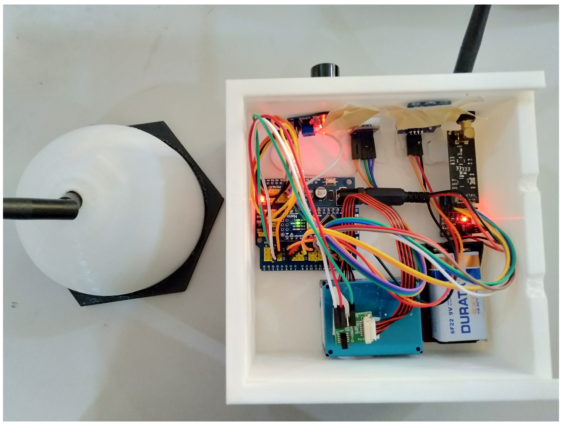


FIGURE 5.8: Air quality monitoring system

FIGURE 5.9: Air quality monitoring UAV

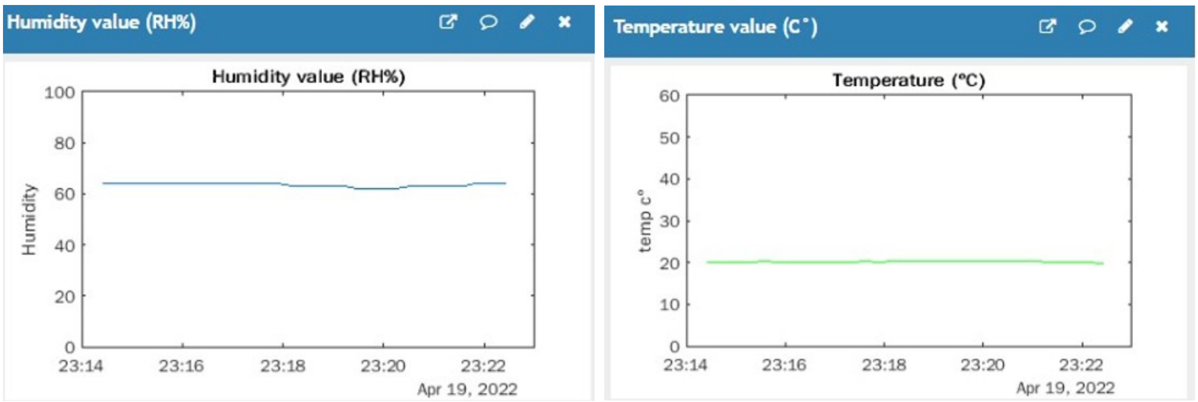
5.5 Results of measurements

The measurements are taken at various times and locations around Tlemcen city. Through the ThingSpeak server, we visualize the state of the air and also save different pollutant concentrations. Figure 5.10 shows all the measurements taken.

Num	Date	Hour	Laltitude	Longitude	O3	CO	NO2	PM2,5	PM10	IQ	IQ_fuzzy
1	19/04/2022	08:55:39	34,883744	-1,34768	0,04	6,01	0,00	18,91	23,91	65	50
2	19/04/2022	09:01:35	34,882982	-1,34792	0,04	3,08	0,00	12,53	18,67	52	43
3	19/04/2022	09:08:07	34,885132	-1,34117	0,06	3,07	0,00	12,35	17,75	58	40
4	19/04/2022	09:16:03	34,889029	-1,33433	0,07	5,05	0,00	21,75	25,50	71	52
5	19/04/2022	09:22:09	34,887632	-1,329002	0,08	4,02	0,00	10,60	10,85	44	30
6	19/04/2022	09:29:38	34,882617	-1,32643	0,09	4,09	0,00	14,25	17,50	56	41
7	19/04/2022	10:10:17	34,877409	-1,32644	0,01	5,00	0,00	10,00	12,00	60	45
8	19/04/2022	22:15:36	34,877216	-1,349164	0,02	6,00	0,00	1,82	3,09	60,00	50
9	19/04/2022	22:22:48	34,871729	-1,33945	0,03	6,50	0,00	3,83	5,00	71,00	52
10	19/04/2022	22:30:56	34,874133	-1,32413	0,03	7,50	0,00	3,00	3,00	95,00	66
11	19/04/2022	22:42:10	34,878929	-1,30114	0,03	7,50	0,00	3,00	3,00	95,00	66
12	19/04/2022	22:50:24	34,88304	-1,30562	0,03	9,20	0,00	8,00	13,00	99,00	67
13	19/04/2022	23:01:32	34,886435	-1,31054	0,01	1,16	0,00	4,00	4,45	17,00	19
14	19/04/2022	23:07:43	34,892309	-1,32361	0,01	3,48	0,00	3,33	4,50	40,00	26
15	19/04/2022	23:09:58	34,900638	-1,32763	0,01	6,67	0,00	3,50	3,50	73,00	51
16	19/04/2022	23:13:48	34,890956	-1,34151	0,01	6,30	0,00	4,50	5,30	69,00	51
17	19/04/2022	23:23:48	34,879956	-1,31326	0,09	4,09	0,00	20,00	27,00	68	51
18	19/04/2022	23:30:48	34,880702	-1,3172	0,07	4,50	0,00	20,00	27,00	68	51

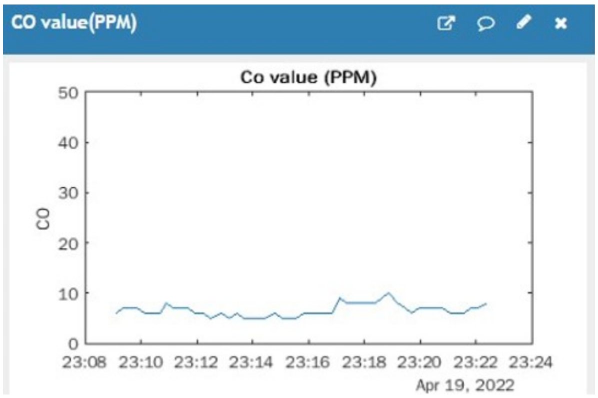
FIGURE 5.10: Air quality measurements

The following figures show the different plots of temperature, humidity, pollutant concentrations, air quality index with conventional and fuzzy logic methods, and real-time air quality category in the server interface.

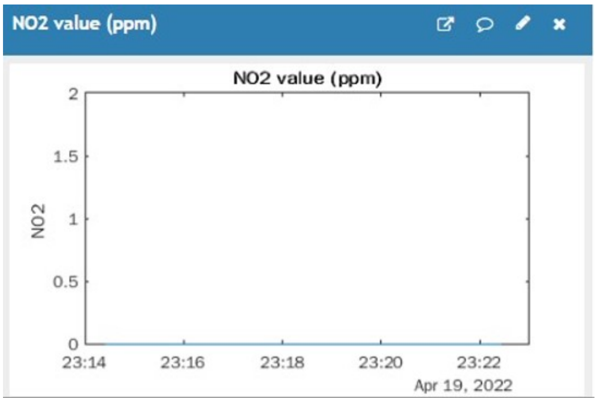


(A) Plot of humidity (B) Plot of temperature

FIGURE 5.11: Humidity and temperature plots

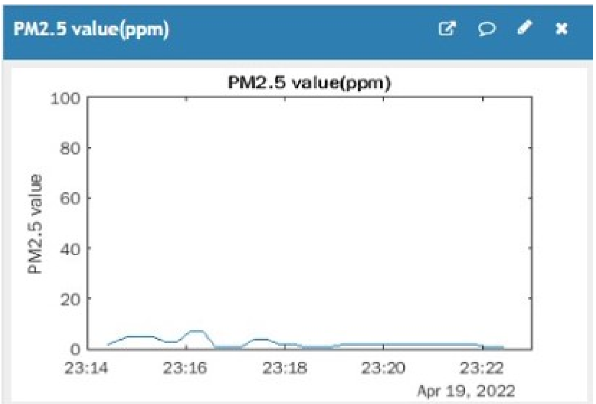


(A) Plot of CO concentration

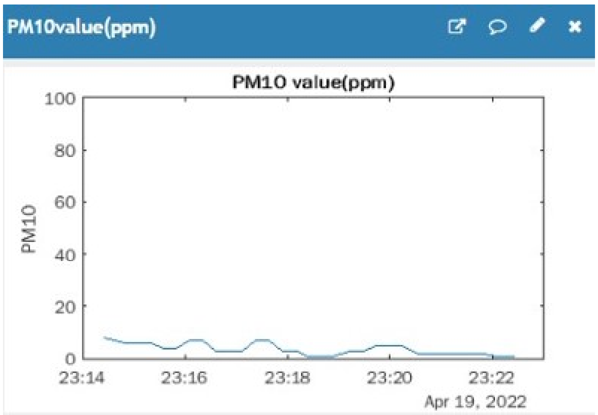


(B) Plot of NO2 concentration

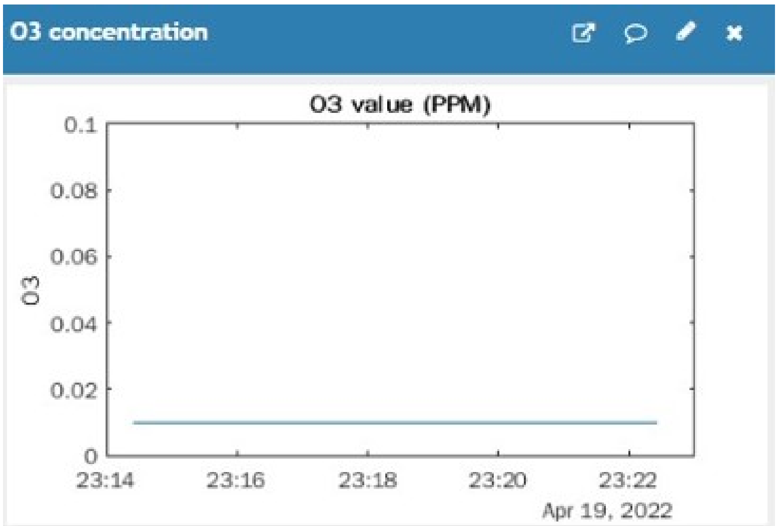
FIGURE 5.12: CO and NO2 concentration plots



(A) Plot of PM2.5 concentration



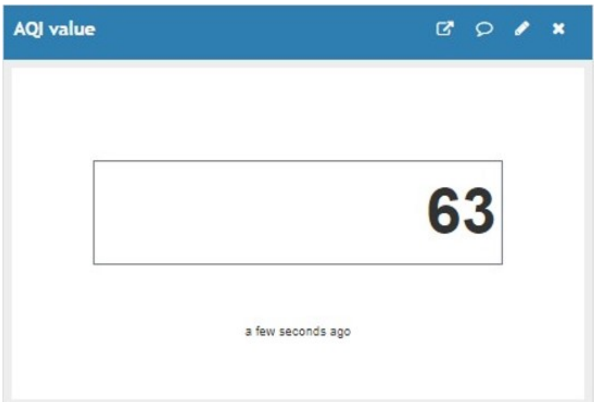
(B) Plot of PM10 concentration



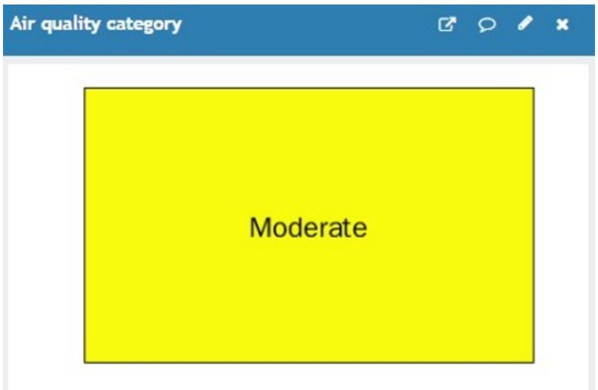
(C) Plot of O3 concentration

FIGURE 5.13: PM2.5, PM10 and O3 concentration plots

The following figure describes the state of the air by air quality index using the two methods.



(A) AQI conventional value

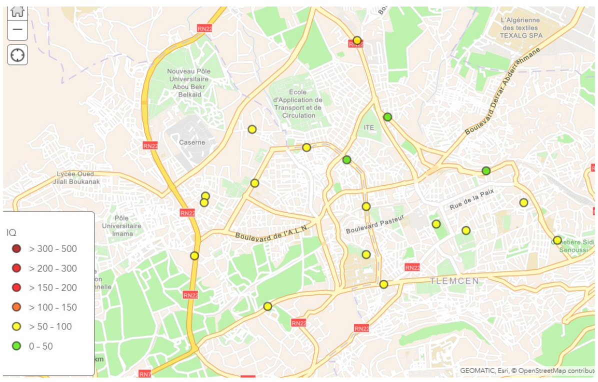


(B) AQI category

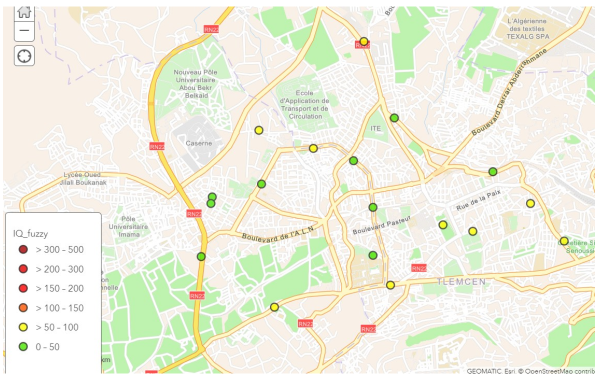
(C) AQI fuzzy value

FIGURE 5.14: Measurement visualisations

We can also visualize the concentrations pollutants and indexes in each location using ArcGIS which is a online geographic information system.



(A) Air quality index in Tlemcen city

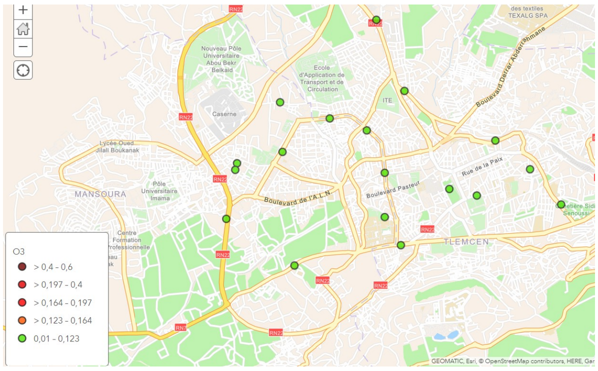


(B) Fuzzy air quality index in Tlemcen city

FIGURE 5.15: Air quality index in Tlemcen city

(A) PM2.5 concentration in Tlemcen city

(B) PM10 concentration in Tlemcen city



(C) O3 concentration in Tlemcen city

(D) CO concentration in Tlemcen city

FIGURE 5.16: Pollutant concentrations in Tlemcen city

5.5.1 Observations and discussion

The air quality in Tlemcen is considered to be above average, as shown in Figure 5.15. The air quality varies from one place to another. It deteriorates in popular areas and during peak hours. In these places, the concentration of particulate matter in the air is quite high. CO and particulate matter are the main pollutants in this city. From Figures 5.13b, 5.13a and 5.12, we can see that the concentration pollutants values are high in the working places. While the concentration of O3 is small and the values of temperature and humidity are stable and within norms, in the whole city, as shown in Figures 5.11 and 5.13c.

We observed that the sensors need one minute to warm up and 30 seconds to get correct results. This time was considered when running the estimation program.

We can see that the values of the air quality index calculated using the conventional process and the fuzzy logic method are very similar. They both put air in the same category. A change in the intervals of the membership fuzzification functions can improve the values calculated by the fuzzy logic approach.

5.6 Conclusion

In the end, after an extensive amount of flight tests and corrections to our quad-copter. We ended up having decent results and for the static marge of drift it can be corrected eventually with micro adjustments to the take off sequence of the drone. The fuzzy-Logic approach is a good method to calculate air quality index. the results are satisfied. it needs only the concentration of pollutants, and can save a lot of time which the opposite of the conventional method.

GENERAL CONCLUSION

Our thesis began with a general overview of air pollution and the consequences of main pollutants. We also looked into the architecture of air quality monitoring systems, specifically the design of air quality monitoring drones and the various technologies utilized to transmit sensor data.

The first part of the realization of a prototype of monitoring of the air quality consists to realize a quad-rotor; We have described the different stages of assembly, as well as the calibration, the configuration, and the control using the software QgroundControl. The second part is to realize the drone payload which is the surveillance system. In the fourth chapter, We described the different components used, we also introduced the IoT and ThingSpeak Cloud for data collection and air quality index display. We have developed a modern method for estimating the air quality index by fuzzy logic.

We evaluated our prototype in the last chapter, starting with several quad-rotor flying tests to check its stability and evaluate its measurement performance. Finally, the air quality monitoring system was tested in different places throughout Tlemcen, with a visualisation of pollutant concentrations and air quality index on the ThingSpeak platform and the geographic information system.

This project can be enhanced by developing another surveillance system. For example, by installing a camera on the level drone that then takes pictures of several areas. By processing the images through artificial intelligence, the air quality of each location can be estimated.

APPENDIX

A

APPENDIX

A.1 Electronic wiring scheme

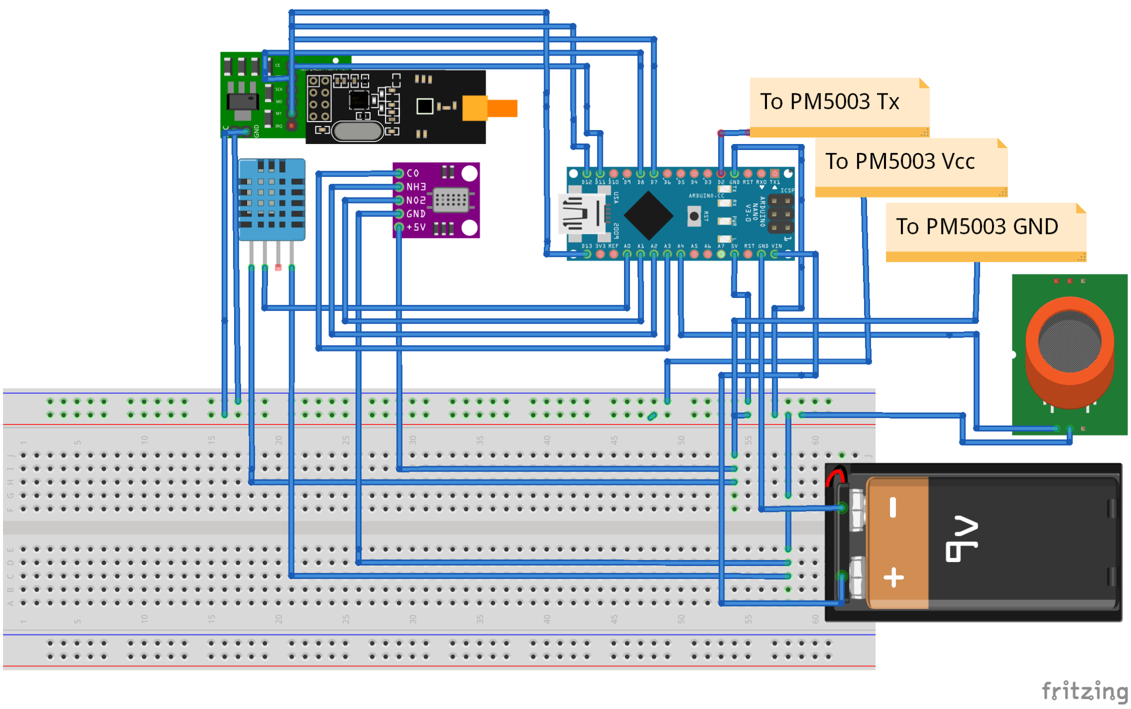


Figure A.1: Electronic Wiring Scheme

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