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*Bachelor thesis*

# Applications of Autonomous Drones for Non-Terrestrial Networks in Remote Areas

Andrés Navarro Pedregal

Tutor
José Alberto Hernández Gutierrez

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## ABSTRACT

this is an abstract

**Keywords:** keyword1, keyword2, keyword3

## ACKNOWLEDGMENTS

Thanks

## AGRADECIMIENTOS

Gracias

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# ACRONYMS

| | |
|---|---|
| 3G | 3rd Generation. |
| 4G | 4th Generation. |
| 5G | 5th Generation. |
| AESA | Spanish Aviation Safety and Security Agency. |
| AI | Artificial Intelligence. |
| AI Act | Artificial Intelligence Act. |
| ANN | Artificial Neural Network. |
| CNN | Convolutional Neural Network. |
| DL | Deep Learning. |
| EASA | European Aviation Safety Agency. |
| EU | European Union. |
| FPV | First Person View. |
| GAN | Generative Adversarial Network. |
| GEO | Geostationary Earth Orbit. |
| HAP | High Altitude Platform. |
| INCOSE | International Council on Systems Engineering. |
| IoT | Internet of Things. |
| LEO | Low Earth Orbit. |
| LTE | Long-Term Evolution. |
| ML | Machine Learning. |
| MTOW | Maximum Takeoff Weight. |
| NTN | Non-Terrestrial Network. |
| RNN | Recurrent Neural Network. |
| SES | Single European Sky. |
| STP | Standard Temperature and Pressure. |
| STS | Standard Training Scenario. |
| UAS | Unmanned Aircraft System. |
| UAV | Unmanned Aerial Vehicle. |
| VLOS | Visual Line of Sight. |

# Part I

# Introduction

# 1. MOTIVATION

**TODO:** write this chapter

# 2. STATEMENT OF THE PROBLEM

Current research in the domainof Non-Terrestrial Network (NTN) primarily focuses on the development of satellite constellations in Geostationary Earth Orbit (GEO) and Low Earth Orbit (LEO) [1]. While these satellites offer significant potential, their high costs and limited customizability render them impractical for many research groups and individual researchers. Moreover, the complexity of launching and maintaining satellites in orbit presents a significant barrier to entry for many interested parties. In contrast, drones present a more affordable and adaptable solution for rapid deployment of communication networks in remote areas as well as low-altitude surveillance and monitoring missions.

The core challenge addressed in this thesis is the lack of widely accessible solutions for the deployment of autonomous drones in remote areas. Presently, available solutions are either expensive, proprietary systems that lack customization, or they require extensive infrastructure, such as ground stations or high-speed internet connectivity. These requirements severely limit the application of drones in areas with minimal or no infrastructure.

This work seeks to address the gap by developing a comprehensive, open-source, and cost-effective solution for autonomous drone missions in remote environments. Given the broad nature of this problem, the scope of this thesis will be narrowed to a specific environment and use case, as outlined below:

- **Environment:** The modeled environment will be a remote area with minimal infrastructure, such as a forest, desert, or mountain. Specifically, the case study will involve an esplanade—a flat area devoid of significant obstacles like buildings or trees—allowing the drone to operate without the risk of collision. Moreover, 4th Generation (4G) or 5th Generation (5G) connectivity will be assumed to be available, enabling the drone to communicate with a ground station.
- **Atmospheric Conditions:** The selected environment will feature a clear sky, with minimal electromagnetic interference from other sources such as drones or aircraft. Additionally, the conditions will approximate Standard Temperature and Pressure (STP) of $15\,^{\circ}\mathrm{C}$ and $1013\,\mathrm{hPa}$.
- **Operational Parameters:** The drone operations will be confined to Visual Line of Sight (VLOS) and an altitude below $120\,\mathrm{m}$, ensuring compliance with current aviation regulations in Spain and most countries. The Maximum Takeoff Weight (MTOW) of the drone will not exceed $25\,\mathrm{kg}$.
- **Hardware:** The drone will be constructed using commercially available, off-the-shelf components to ensure affordability and ease of replication for other research groups and individuals.
- **Application:** This work will focus on the application of drones in human rescue missions, such as search and rescue operations in disaster-stricken areas or monitoring remote environments for signs of danger. While there are other potential applications of drones in remote areas, human rescue offers significant societal benefits.

# 3. OBJECTIVES

The primary aim of this thesis is to provide the research community and humanitarian organizations with an open-source, modular, and customizable drone capable of operating in remote areas. The drone will be designed to be cost-effective, user-friendly, and competitive with other market offerings. It will incorporate the latest advancements in drone technology to ensure optimal performance and reliability.

In addition, a software platform will be developed to enable the operation of the drone for reconnaissance tasks. The platform will support multiple drones, allowing for the deployment of a coordinated swarm to conduct surveillance and monitoring missions effectively. The software will be user-friendly, enabling researchers and humanitarian organizations to program the drones for specific tasks easily.

To achieve these objectives, the following specific aims will be pursued:

- The design must be modular and customizable, enabling easy modifications to adapt the drone for different applications.
- The components utilized in the drone should be off-the-shelf and readily available, facilitating straightforward assembly and repairs.
- The drone must be capable of autonomous flight to enable operations in remote areas where manual control is challenging.
- The design will incorporate the latest advancements in drone technology, ensuring competitiveness with other market offerings.
- The drone must be capable of communicating with a ground station to facilitate remote control.
- The software platform should be programmable to perform specific tasks, such as reconnaissance of designated areas and monitoring of particular parameters.
- The software platform must support multiple drones, allowing for the deployment of a coordinated swarm to conduct reconnaissance tasks effectively.

# 4. DOCUMENT STRUCTURE

**TODO:** Write this chapter when all the document is finished.

# 5. METHODOLOGICAL FRAMEWORK

The methodological framework employed in this thesis is grounded in the V-model as established by the International Council on Systems Engineering (INCOSE) [2] for project development. The V-model offers a rigorous and structured method that ensures all project facets are considered, facilitating timely and budget-compliant completion. This is achieved through a comprehensive development process, enabling clear validation and verification of initial requirements at every stage.

The methodology is segmented into seven key components which can be summarized as follows:

1. **Identification of User Requirements**: A detailed analysis of the problem statement is conducted to identify the primary issues and potential solutions. Moreover, the user requirements are defined to ensure that the proposed solution aligns with the objectives of the project.

2. **System Design**: The system architecture is developed based on the user requirements, ensuring that the proposed solution is feasible and aligns with the project's objectives. This phase includes a detailed overview of the system components and their interconnections. Requirements are formulated to satisfy the previously defined solution requirements. This phase includes a high-level overview of the components of the proposed solution, the justification for their selection, and the interconnections among them.

3. **Component Design**: Building upon the high-level architecture of the solution, a more detailed approach is outlined for each component, taking into account their specific power and data transmission needs. This culminates in a comprehensive architecture of the solution. Furthermore, a detailed overview of the components is provided, including the rationale for their selection and the interconnections among them.

4. **Implementation**: The proposed solution is implemented and manufactured utilizing available tools while simultaneously integrating the necessary electrical components. This phase includes a detailed description of the implementation process, including the tools and materials used, as well as the integration of electrical components. The development of software and hardware components is also detailed.

5. **Component Testing**: The functionality of each component is verified in a standalone mode, with detailed information provided regarding the verification process.

6. **System Testing**: The methodology for conducting flight tests and subsequent analyses is elaborated. System integration is performed by assessing communication between module pairs to ensure that data can be transmitted freely and utilized effectively.

7. **Acceptance Testing**: Validation of the initial requirements is conducted to confirm that all solution requirements have been met. This phase also includes preparations for potential future enhancements.

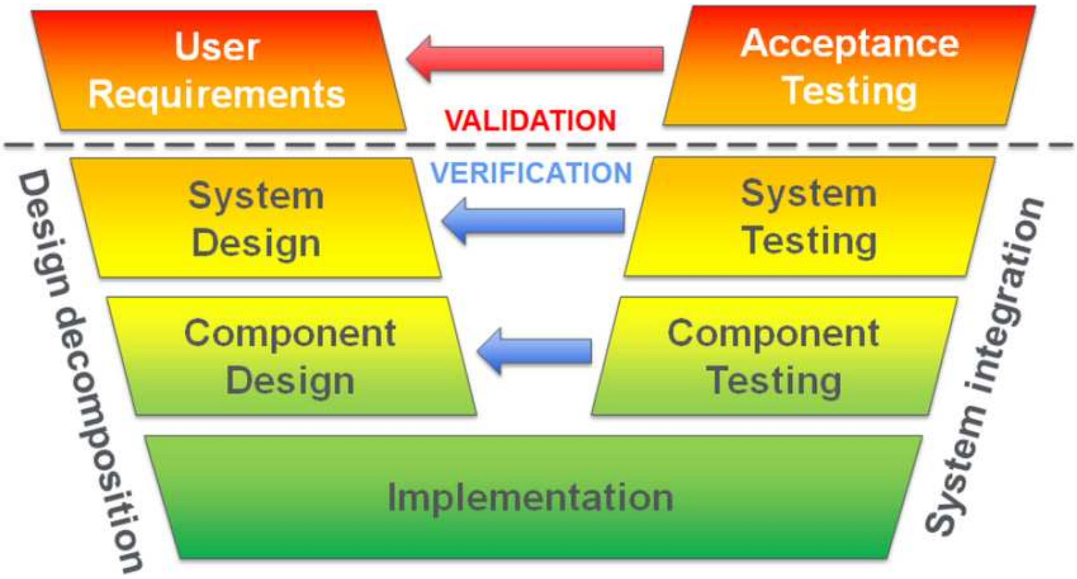


Figure 5.1. *Methodological framework based on the V-model from INCOSE with the different stages of the project development process[3]*

Moreover, a graphical representation of the V-model is provided in Figure 5.1 to illustrate the methodology's structure and the relationship between the various stages.

# Part II

# Theoretical Background

# 6. NON-TERRESTRIAL NETWORKS

NTNs represent a groundbreaking approach in wireless communication, utilizing aerial and space-based platforms to deliver connectivity services. These platforms can operate at varying altitudes, from a few hundred meters to several kilometers above ground, offering key advantages over traditional terrestrial networks, such as expanded coverage, increased capacity, and greater flexibility.

NTNs provide a promising solution to meet the rising demand for wireless access in remote and underserved areas. By leveraging aerial and space platforms, NTNs can extend the reach of conventional terrestrial networks, offering connectivity where traditional infrastructure is either difficult or impossible to deploy. These platforms are available in several configurations, including High Altitude Platforms (HAPs), LEO satellites, and GEO satellites, each with distinct benefits in terms of coverage, capacity, and latency, making them suitable for various use cases. In Figure 6.1, we illustrate the different types of NTNs based on altitude and platform type as well as their interaction with other network elements such as ground stations, Unmanned Aerial Vehicles (UAVs), Internet of Things (IoT) devices, etc.

## 6.1 Geostationary Satellites

GEO satellites operate at an altitude of approximately 35 786 km above the Earth's equator. These satellites maintain a fixed position relative to the Earth's surface, as they orbit at the same rate as the planet's rotation. GEO satellites offer extensive coverage, often spanning entire continents, and are widely used for telecommunications, broadcasting, and weather monitoring.

Compared to LEO satellites, GEO satellites offer broader coverage and higher capacity, making them ideal for applications like direct-to-home television, satellite radio, and broadband internet access. Their capacity to cover large regions makes GEOs integral to global communications infrastructure.

A key advantage of GEO satellites is their ability to support high-capacity services for many users, making them valuable for broadcasting live events, such as sports and concerts, or delivering high-definition video content worldwide. As a fundamental part of the global media and communication ecosystem, GEO satellites are expected to continue playing a vital role in providing connectivity to remote and underserved regions.

## 6.2 Low-Earth Orbit Satellites

LEO satellites operate at altitudes between 160 km and 2000 km above the Earth. Orbiting at high speeds, these satellites provide global coverage, making them ideal for delivering connectivity to remote and underserved regions. LEO satellites offer several advantages over traditional GEO satellites, including lower latency, higher capacity, and reduced infrastructure costs.

Deployed in constellations consisting of hundreds or thousands of satellites, LEO satellites work together to provide continuous coverage. These satellites communicate through inter-satellite links, allowing data to be relayed seamlessly across the constellation. LEO satellites are well-suited for delivering broadband internet access in areas where traditional infrastructure is difficult to establish.

One of the primary advantages of LEO satellites is their low latency, enabling real-time communication and supporting applications that require minimal delay, such as online gaming, video conferencing, and autonomous vehicle systems. Additionally, LEO satellites offer high-speed internet connectivity to users in remote locations, granting access to online services, educational platforms, and e-commerce opportunities. As a critical part of the emerging NTN ecosystem, LEO satellites are expected to play a key role in bridging the global digital divide.

## 6.3 High-Altitude Platforms

HAPs operate at altitudes ranging from a few hundred meters to several kilometers above the Earth. These platforms may consist of balloons, airships, or UAVs. They provide several benefits compared to traditional terrestrial networks, including broader coverage, increased capacity, and lower infrastructure costs. HAPs can be deployed swiftly to offer connectivity in remote or underserved areas, making them an effective tool for reducing the digital divide.

Additionally, HAPs can provide temporary connectivity in disaster-stricken regions or during large-scale events. Rapid deployment allows emergency responders to coordinate efforts efficiently. They can also extend the coverage of existing networks in rural areas, where conventional infrastructure is costly or challenging to install.

Advances in UAV technology have enabled the development of autonomous HAPs equipped with Long-Term Evolution (LTE) or 5G base stations, flying at altitudes of up to 20 km. These platforms cover vast areas and support a range of applications, making them ideal for remote and underserved locations where deploying traditional infrastructure is not practical.

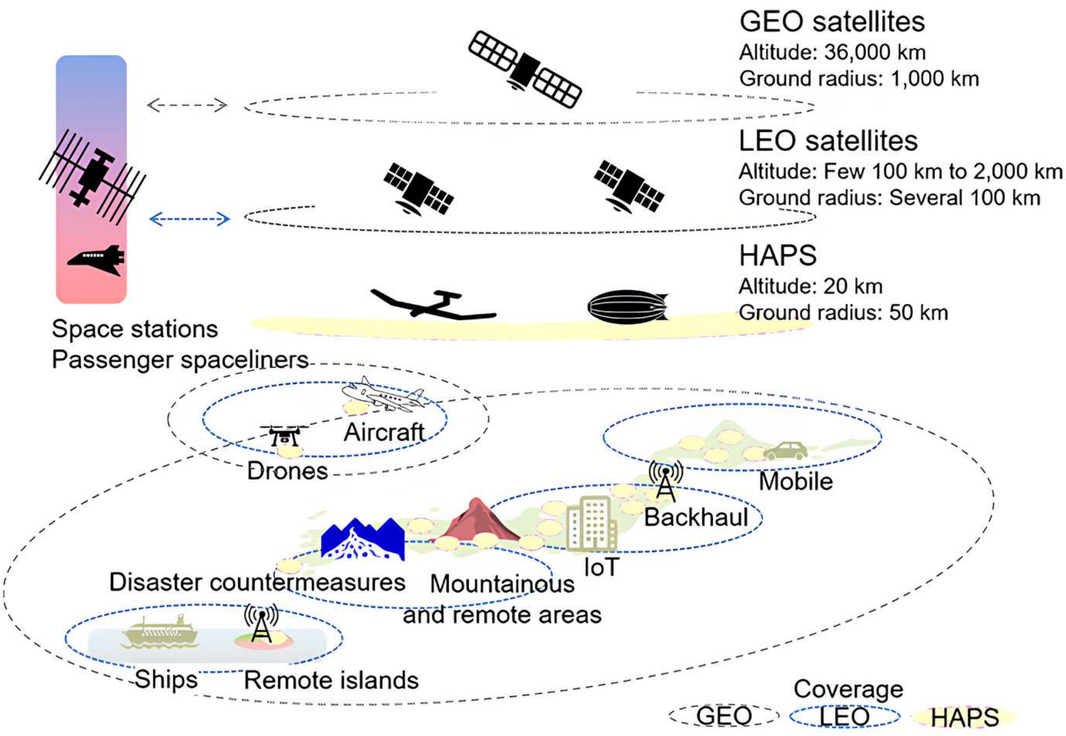


Figure 6.1. *Types of NTNs based on altitude and platform type. HAPs, LEOs satellites, and GEOs satellites interact with other network elements to provide connectivity services. [6]*

# 7. UNMANNED AERIAL VEHICLES

The term UAV encompasses a diverse range of aircraft, from compact quadcopters to larger fixed-wing models. What primarily distinguishes UAVs from conventional aircraft is that UAVs are either remotely piloted or autonomously controlled, whereas traditional aircraft are operated by human pilots. This autonomy enables UAVs to be deployed in scenarios where human presence is either impractical or hazardous, such as military operations or environments with significant risk.

UAVs serve various purposes across multiple industries, including surveillance, reconnaissance, search and rescue missions, and scientific research. Additionally, they have become invaluable in sectors like agriculture, forestry, and environmental monitoring. In recent years, UAVs have gained popularity among hobbyists for recreational flying and personal projects.

## 7.1 Types of Unnamed Aerial Vehicles

In line with the classification presented by the European Aviation Safety Agency (EASA) [4], UAVs can be categorized into three main types, each based on size, weight, physical design, and operational capabilities:

- **Fixed-wing UAVs:** These aircraft feature fixed wings and function similarly to conventional airplanes. They tend to be larger and designed for long-duration flights, making them suitable for extended missions like surveillance, reconnaissance, and mapping. However, they require runways for takeoff and landing, and cannot hover in place, limiting their versatility in confined spaces.
- **Rotary-wing UAVs:** Equipped with multiple rotors, these UAVs can take off and land vertically. They are typically smaller and more agile, making them ideal for close-range missions like aerial photography, search and rescue, and surveillance. However, their limited range and endurance compared to fixed-wing UAVs restrict their use in long-duration missions.
- **Hybrid UAVs:** Combining the features of both fixed-wing and rotary-wing designs, hybrid UAVs can take off and land vertically like rotary-wing models while achieving greater range and endurance through fixed-wing flight. These aircraft are ideal for missions requiring versatility, such as reconnaissance and mapping. Despite their advantages, they are more complex and costly to operate than single-type UAVs.

Figure 7.1 illustrates the different UAVs types based on their design and intended applications.

In Table 7.1, a detailed comparison of fixed-wing, rotary-wing, and hybrid UAVs is presented across various performance metrics, including size, range, endurance, cost, and ease of operation. The table provides insights to help in selecting the appropriate UAV for specific mission requirements, depending on factors like payload, range, and maneuverability.

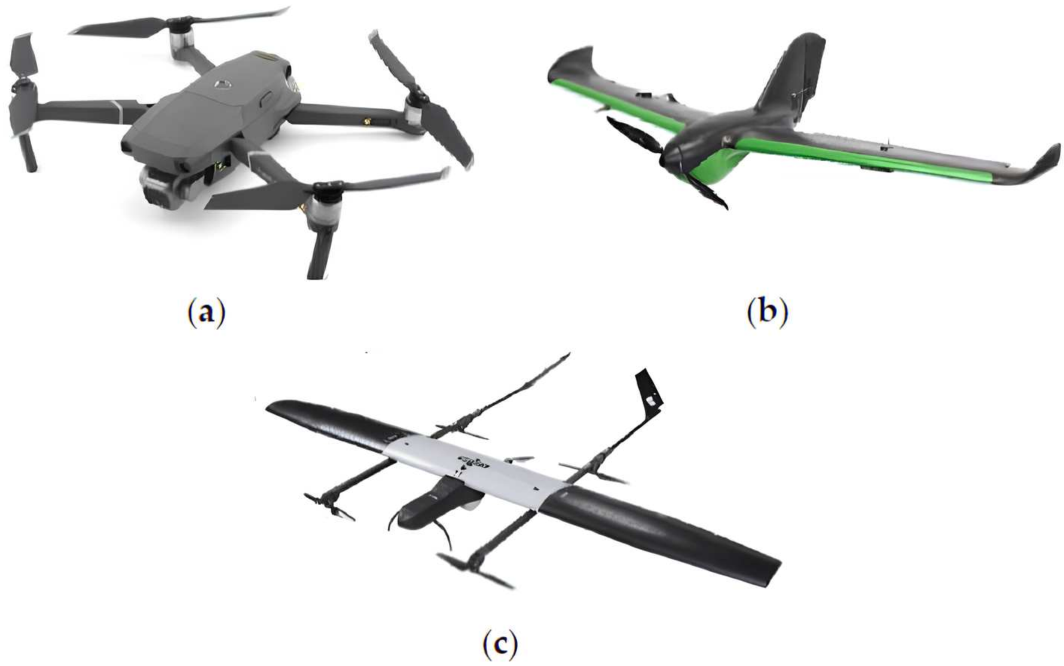


Figure 7.1. *Types of uav based on their design and intended use [5]. a. Rotary-wing UAV, b. Fixed-wing UAV, c. Hybrid UAV*

| **Metric** | **Fixed-wing** | **Rotary-wing** | **Hybrid** |
|---|---|---|---|
| Size | Moderate | Small | Large |
| Range | Long | Short | Moderate |
| Endurance | High | Low | Moderate |
| Payload capacity | High | Low | Moderate |
| Maneuverability | Low | High | Moderate |
| Ease of use | Moderate | High | Low |
| Maintenance | Moderate | Low | High |
| Runway requirement | Yes | No | Yes |
| Cost | Moderate | Low | High |

Table 7.1. *Comparison of fixed-wing, rotary-wing, and hybrid UAVs across various performance metrics*

## 7.2 Applications of Unmanned Aerial Vehicles

UAVs have a wide range of applications across different industries, leveraging their versatility, maneuverability, and autonomy. Some common applications of UAVs include:

- **Aerial photography and videography:** UAVs equipped with high-resolution cameras are used for capturing aerial images and videos for various purposes, including filmmaking, real estate, and landscape photography.
- **Agriculture:** UAVs are employed in precision agriculture to monitor crop health, assess soil conditions, and optimize irrigation and fertilization practices. They can provide valuable insights to farmers for improving crop yield and reducing resource wastage.
- **Search and rescue:** UAVs equipped with thermal imaging cameras and other sensors are used in search and rescue operations to locate missing persons, assess disaster-affected areas, and deliver essential supplies to remote locations.
- **Infrastructure inspection:** UAVs are utilized for inspecting critical infrastructure like bridges, power lines, and pipelines. They can access hard-to-reach areas and capture detailed images for assessing structural integrity and identifying maintenance needs.
- **Environmental monitoring:** UAVs are deployed for monitoring environmental parameters like air quality, water quality, and wildlife populations. They can collect data in remote or hazardous environments, providing valuable insights for conservation efforts and scientific research.
- **Disaster response:** UAVs play a crucial role in disaster response by providing real-time situational awareness, mapping affected areas, and coordinating emergency operations. They can assist in assessing damage, locating survivors, and delivering aid to disaster-stricken regions.
- **Military and defense:** UAVs are extensively used in military and defense applications for reconnaissance, surveillance, target acquisition, and combat operations. They offer a cost-effective and low-risk alternative to manned aircraft in high-risk environments.
- **Delivery services:** UAVs are increasingly being used for last-mile delivery of goods and services. Companies like Amazon and UPS are exploring the use of UAVs for delivering packages to customers in urban and rural areas.

# 8. DEEP LEARNING

Deep Learning (DL) is a subfield of Machine Learning (ML) that focuses on the development of algorithms and models inspired by the structure and function of the human brain. These algorithms are designed to learn from data, identify patterns and relationships, and make predictions or decisions without explicit instructions. DL algorithms are characterized by their ability to automatically discover and extract features from raw data, enabling them to perform complex tasks such as image recognition, speech recognition, and natural language processing.

DL has revolutionized various industries and domains, including healthcare, finance, transportation, and entertainment. By leveraging the power of DL, organizations can analyze large datasets, extract valuable insights, and automate complex tasks, leading to improved decision-making, enhanced user experiences, and optimized processes. From self-driving cars and virtual assistants to medical diagnostics and fraud detection, DL is transforming the way we interact with technology and the world around us.

Furthermore, DL plays a crucial role in enabling UAV autonomy, allowing drones to perform tasks such as navigation, obstacle avoidance, and object recognition without human intervention. By integrating DL algorithms into UAV systems, researchers and developers can enhance the capabilities and efficiency of drones, enabling them to operate in complex environments and execute sophisticated missions.

## 8.1 Deep Learning Techniques

DL encompasses a wide range of techniques and architectures that enable machines to learn from data and make decisions. Some of the most common DL techniques include:

- **Artificial Neural Network (ANN):** ANN are computational models inspired by the structure and function of the human brain. They consist of interconnected nodes, or neurons, organized in layers, with each neuron performing a simple computation. ANN can learn complex patterns and relationships in data through a process called backpropagation, where errors are propagated back through the network to adjust the model's parameters. ANN are used in a variety of tasks, such as classification, regression, and clustering.

- **Convolutional Neural Network (CNN):** CNN are a type of ANN designed for processing and analyzing visual data, such as images and videos. They use convolutional layers to extract features from input data, pooling layers to reduce spatial dimensions, and fully connected layers to make predictions. CNN are widely used in image recognition, object detection, and image segmentation tasks.

- **Recurrent Neural Network (RNN):** RNN are a type of ANN designed for processing sequential data, such as time series, text, and speech. They have feedback connections that allow information to persist over time, enabling them to capture temporal dependencies in data. RNN are used in natural language processing, speech recognition, and machine translation tasks.

- **Generative Adversarial Network (GAN):** GAN are a type of DL model that consists of two neural networks, a generator and a discriminator, trained adversarially. The generator generates synthetic data samples, while the discriminator distinguishes between real and fake samples. GAN are used in image generation, style transfer, and data augmentation tasks.

These techniques form the foundation of DL and are used in a wide range of applications across various domains, enabling machines to perform complex tasks and make intelligent decisions. In the context of NTN and UAVs, DL techniques can enhance network performance, optimize resource allocation, and enable autonomous operation, leading to more efficient and reliable systems. Furthermore, DL can enable UAVs to perform tasks such as navigation, object detection, and mission planning with high accuracy and efficiency, making them valuable tools for a wide range of applications (e.g., surveillance, monitoring, and disaster response).

# Part III

# State of the art

# 9. HISTORICAL DEVELOPMENT

**TODO:** write this chapter

# 10. TYPES & TECHNOLOGIES

**TODO:** write this chapter

# 11. MODERN TRENDS

**TODO:** write this chapter

# 12. REGULATORY FRAMEWORK

The regulatory framework governing drones is a complex and dynamic area, influenced by various laws and regulations that differ from country to country. Generally, drone operations are regulated by aviation authorities responsible for ensuring safe and responsible usage.

## 12.1 Relevant Institutions

### 12.1.1 European Aviation Safety Agency (EASA)

The EASA [7] plays a crucial role in harmonizing aviation safety standards across all European Union (EU) member states. Its primary objective is to maintain a consistent and high level of safety in civil aviation operations throughout the EU. EASA achieves this through the establishment and enforcement of common regulations applicable to all member states. Notably, for the standardization of Unmanned Aircraft System (UAS), EASA has implemented Regulations (EU) 2019/947 [4] and (EU) 2019/945 [8].

### 12.1.2 Spanish Aviation Safety and Security Agency (AESA)

In Spain, the Spanish Aviation Safety and Security Agency (AESA) [9] serves as the national regulatory authority, overseeing compliance with civil aviation standards within the aerospace sector. AESA plays a critical role in promoting the development and application of aviation legislation, ensuring that the Spanish civil aviation system upholds the highest safety, quality, and sustainability standards. In instances of non-compliance with aviation regulations, AESA possesses the authority to enforce sanctions.

## 12.2 Applicable Legislation

### 12.2.1 Implementing Regulation (EU) 2019/947

The Implementing Regulation (EU) 2019/947 [4] establishes the operational rules and requirements for UAS within the EU. It provides a legal framework for the utilization of UAS across various operational categories, outlining requirements for operational authorizations and risk assessments where applicable. The regulation sets standards for remote pilot competency, operational procedures, and safety management to conduct UAS flights safely and effectively.

Additionally, it integrates with the Delegated Regulation (EU) 2019/945 [8] by defining operational requirements related to the UAS classes established within it. The regulation details specific operational limitations and conditions for each UAS class, including the management of UAS in classes C0 through C4. It also includes provisions for the safe integration of newly introduced UAS classes under Delegated Regulation (EU) 2020/1058 [10], specifically classes C5 and C6.

Moreover, this regulation addresses the procedures for UAS operators from third countries (non-EASA member states) wishing to operate within the Single European Sky (SES) airspace, ensuring alignment with EU standards and safety regulations.

### 12.2.2 Delegated Regulation (EU) 2019/945

The Delegated Regulation (EU) 2019/945 [8] defines the rules and standards for UAS within the EU. It specifies the types of UAS that require certification regarding design, production, and maintenance. This regulation also provides guidelines for the commercialization of UAS intended for use in the Open category, as well as for remote identification accessories (e.g., Drone Remote ID). Furthermore, it outlines the requirements for the design and manufacture of UAS intended for operations defined in the Implementing Regulation (EU) 2019/947.

### 12.2.3 Regulation (EU) 2024/1689: Artificial Intelligence Act (AI Act)

The Artificial Intelligence Act (AI Act) of the EU [11], which came into force on the 1st of August 2024, aims to ensure that Artificial Intelligence (AI) systems are safe, transparent, and ethical, while fostering innovation and protecting fundamental rights as stated in the Delegated Regulation (EU) 2024/1689 [12]. The AI Act categorizes AI systems by risk, imposing strict requirements on high-risk applications, particularly in aviation, which may affect public safety and fundamental rights. These requirements encompass robust risk management, transparency, human oversight, and data governance, ensuring that AI systems are reliable and secure.

The AI Act introduces significant compliance obligations that could escalate development costs and timelines. High-risk systems must adhere to stringent standards to access the EU market, potentially challenging innovation but ultimately aiming to build trust and facilitate broader adoption of AI technologies within the EU.

## 12.3 Operational Categories

The Regulation (EU) 2019/947 [4] classifies UAS into three distinct categories:

- **Open Category:** The least restrictive category, designed for low-risk operations, includes activities such as recreational flying and commercial operations posing minimal risk to people and property. Operators must adhere to specific limitations (e.g., flying below 120 meters, maintaining VLOS). UAS must weigh under 25 kg, and pilots must ensure that the drone does not fly over people or in restricted areas. No prior authorization is required, though registration and remote pilot training are compulsory for all operations, except for drones weighing less than 250 g that lack a camera or sensor.

- **Specific Category:** This category covers medium-risk operations necessitating a more detailed assessment. It includes operations that may involve flying over people or in restricted areas, provided mitigation procedures are in place. Operators must conduct a risk assessment and obtain an operational authorization known as Standard Training Scenario (STS) from AESA. Requirements for UAS and pilot qualifications may vary based on the specific risk assessment and operational procedures defined within it.

- **Certified Category:** Designed for high-risk operations, this category involves stringent requirements comparable to those for manned aviation. UAS must meet specific certification standards and operators must comply with strict safety regulations. This category often includes advanced training requirements and operational procedures similar to those for commercial air transport.

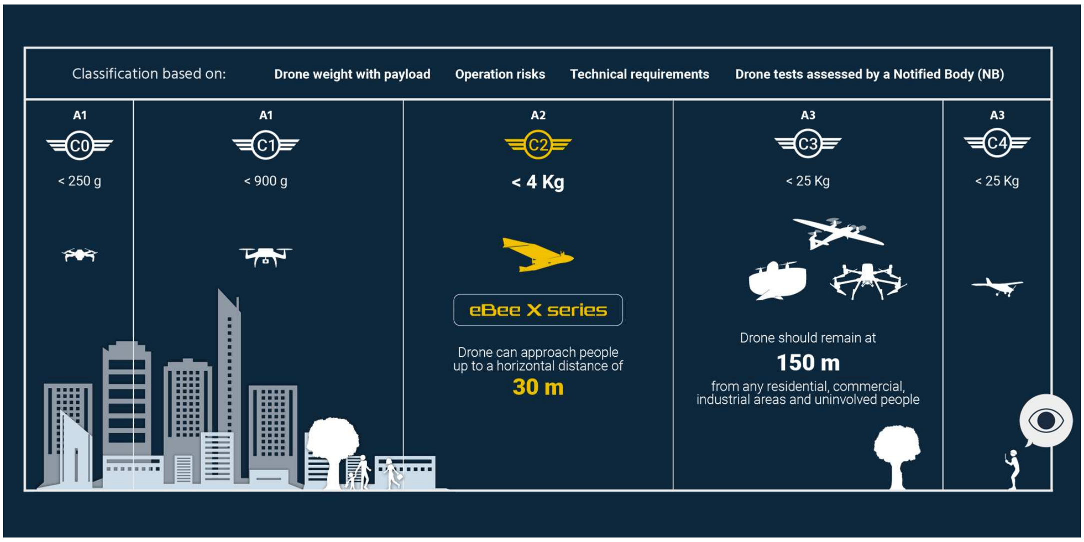


Figure 12.1. *EU Regulations Open Category chart describing the subcategories A1, A2, and A3 with their respective operational limitations [13]*

### 12.3.1 Open Category

This work will focus on civil UAS that fall under EASA's Open Category, although some findings may be applicable to other categories with appropriate regulatory adjustments. Within the Open Category, three subcategories differentiate based on associated risk, aircraft weight, and operational limits:

1. **A1**: UAS with a MTOW of less than 250 g that can fly over people but not over assemblies of people.
2. **A2**: UAS with an MTOW of less than 4 kg that can fly close to people but must maintain a horizontal distance of 30 meters (5 meters in low-speed configuration).
3. **A3**: UAS with an MTOW of less than 25 kg that must maintain a horizontal distance of 150 meters from residential, commercial, industrial, or recreational areas.

Check Figure 12.1 for a visual representationof the Open Category subcategories.

Moreover, additional rules applicable to all three subcategories include:

- The maximum height must not exceed 120 meters above ground level, as the lower limit for general aviation is 150 meters. This leaves only a 30-meter separation between manned aviation and UAS.
- Operators must always maintain VLOS unless the aircraft is in "follow me" mode or the pilot is using First Person View (FPV) goggles.
- Operators must register if the UAS weighs more than 250 g or if the aircraft is equipped with a camera or sensor.
- The aircraft must possess a remote identification ID, which is standard in all C1-C6 categories, with the exception of C4 and privately built aircraft.

# Part IV

# Methodology

# 13. REQUIREMENTS

Based on careful analysis of the conclusions from the current trends in UAVs outlined in Chapter 11 and the objectives reviewed in Chapter 3, the following requirements are established for the high-level system as well as the detailed requirements for the UAV, control station, and software platform.

## 13.1 High-level System Requirements

The high-level system requirements are as follows:

- The system must be able to operate in remote areas with limited infrastructure, such as roads, electricity, and internet connectivity.
- The system must be able to be monitored remotely, with the ability to communicate with a ground station via a 4G or 3rd Generation (3G) connection.
- The system must be cost-effective, with the ability to be assembled and disassembled easily, and to be repaired and maintained with minimal effort.
- The system must be modular, allowing for the integration of different sensors and payloads for different applications, as well as, the scalability of the system to include multiple UAVs working together in a coordinated manner.
- The system must be able to perform reconnaissance tasks autonomously, with the ability to take off, land, and navigate given a set of waypoints.
- The system must comply with the applicable regulatory framework for UAVs in the country of operation, Spain, as well as the EU regulations. See Chapter 12 for more information.

## 13.2 Unmanned Aerial Vehicle Requirements

The UAV requirements are as follows:

- The UAV must be able to be controlled remotely, with the ability to communicate with a ground station in real-time.
- The UAV must be able to take off, land, and navigate autonomously, with the ability to update its flight plan in real-time.
- The UAV must be able to process data in real-time, with the ability to relay the information to the ground station.
- The UAV must be able to carry different payloads and sensors for different applications up to a maximum payload weight of 2 kg, with the ability to adapt to different reconnaissance tasks.
- The UAV must be able to fly for a minimum of 30 minutes, without the need for recharging.
- The UAV must be have a failsafe mechanism, that is it must be able to return to the ground station in case of loss of communication or other critical failures.

- The UAV must be able to keep a fixed altitude and position.
- The UAV must comply with the EASA regulations for the Open Category, with a maximum limit set at 25 kg of MTOW and 3 meters of wingspan.
- The UAV must be able to perform reconnaissance tasks, such as mapping, surveillance, and monitoring the environment.

## 13.3 Control Station Requirements

The control station requirements are as follows:

- The control station must be able to receive telemetry data from the UAV in real-time, with the ability to send commands to the UAV to update its flight plan.
- The control station must be able to be used remotely, with the ability to communicate with the UAV via a 4G or 3G connection.
- The control station must be able to create a geofence around the area of operation, with the ability to monitor the UAV's position and altitude in real-time.
- The control station must have the capability be able to track multiple UAVs simultaneously, with the ability to coordinate their flight plans and tasks.
- The control station must log all telemetry data and flight information, with the ability to analyze the data and generate reports.

## 13.4 Software Platform Requirements

The software platform requirements are as follows:

- The software platform must be able to run on a variety of operating systems, with the ability to communicate with the UAVs and the control station in real-time.
- The software platform must be able to be used remotely, with the ability to access the UAVs and the control station via a 4G or 3G connection.
- The software platform must be reliable, secure, and easy to use, allowing for the programming of the UAVs to perform specific tasks and the coordination of multiple UAVs in a swarm.
- The software platform must be customizable, allowing for the integration of new features and the modification of existing ones, as well as, the addition of new UAVs to the system and different types of reconnaissance tasks.
- The software platform must have alerting and notification capabilities, with the ability to send alerts and notifications to the user in case of critical events or failures.
- The software platform must have a user-friendly interface, with the ability to display telemetry data and flight information in real-time, as well as, the ability to monitor the UAVs in real-time.

# 14. DESIGN

**TODO:** write this chapter

# 15. IMPLEMENTATION

**TODO:** write this chapter

# 16. TESTING

**TODO:** write this chapter

# Part V

# Results

# Part VI

# Conclusions

# 17. CONCLUSIONS

**TODO:** write this chapter

# 18. FUTURE WORKS

**TODO:** write this chapter

# 19. SOCIO-ECONOMIC ENVIRONMENT

**TODO:** write this chapter

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