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University Degree in Data Science and Engineering and Telecommunication Technologies Engineering
2024 – 2025

Bachelor thesis

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

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Leganés, 2025

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ABSTRACT

this is an abstract

Keywords: keyword1, keyword2, keyword3

ACKNOWLEDGMENTS

Thanks

AGRADECIMIENTOS

Gracias

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Part I

Introduction

1. MOTIVATION

2. STATEMENT OF THE PROBLEM

primary problem: the use of autonomous drones for remote areas is not widespread due to the lack of infrastructures, software and cheap drones.

moreover, the lack of specific knowledge and the steps to create a drone from scratch is a high barrier of entry for many people.

exisitng solutions as the dji drones are expensive and not open source, and not customizable which limits the potential of the drones. moreover the modularity of the drones is limited so the applicaitons are just a subset of the potential applications for example reconnaissance, surveillance, agriculture, etc.

Moreover, working in remote areas is often not possible due to the lack of infrasturctures, such as roads, electricity, internet, etc. This makes it difficult to use drones in these areas.

as this problem is broad, it needs to be narrowed down to a specific problem that can be solved in this thesis. The environment that will be modeled in this thesis will have the following characteristics:

TODO: complete the list of characteristics of the environment that will be modeled in this thesis

- internet connection via 4G or 3G will be available

3. OBJECTIVES

The main goal of this thesis is to develop a open-source, modular and customizable drone that can be used in remote areas. The drone will be able to fly autonomously and will be able to communicate with a ground station. The drone will be able to be controlled remotely and will be able to be programmed to perform specific tasks. The drone will be able to be used in a variety of applications, such as reconnaissance, surveillance, agriculture, humanitarian aid, etc.

Moreover, a software platform will be developed that will allow the drone to be programmed to perform reconnaissance tasks and the software will be designed to support multiple drones to create a swarm of drones that can be used to perform reconnaissance tasks in a coordinated way.

The drone will be designed to be easy to assemble and disassemble and will be designed to be easy to repair and maintain. The drone will be designed to be cheap and will be designed to be easy to customize and modify.

4. DOCUMENT STRUCTURE

5. METHODOLOGY APPROACH

TODO: need to rephrasea all this The methodology approach used in this thesis is based on the V-model as outlined by the International Council of System Engineering (INCOSE) standard for project development. The V-model is a rigorous and structured approach to project development that ensures that all aspects of the project are considered and that the project is completed on time and within budget. It is achieved by a thorough development process, facilitating clear validation and verification of initial requirements at each stage.

The methodology is divided into seven parts:

TODO: add image of the V-model

1. Identification of Solution Requirements: Before taking any actions, it is crucial to understand what can be achieved and the rationale behind it. To this end, the author has focused on deriving valuable insights from the reviewed literature in the State of the Art (SOT A) and identifying critical scenarios. Subsequently, and in conjunction with the thesis objectives and the applicable regulatory framework, a list of solution requirements is created. This list will later serve as a benchmark for validating the proposed solution.

2. Identification of System Requirements: Technical requirements are formulated to meet the previously established solution requirements. This includes a high-level overview of the proposed solution's components, the rationale for their selection, and their interconnections.

3. Identification of Component Requirements: Building on the high-level architecture of the solution, a more detailed approach is outlined for each component, considering their specific power and data transmission needs. This results in a detailed architecture of the solution.

4. Manufacturing and Implementation: The proposed solution is manufactured using available tools, while simultaneously integrating the necessary electrical components.

5. Component Verification: Each component's functionality is verified in standalone mode, with detailed information provided on the verification process.

6. Integration Testing and Flight Testing: The methodology for conducting flight tests and post-flight analysis is described. System integration is performed by checking communication between module pairs to ensure that data can travel freely and be used effectively.

7. Deployment and Preparation for Future Upgrades: Validation of the initial requirements is conducted to ensure that all solution requirements have been addressed. This step also includes preparations for potential future upgrades.

Part II

State of the art

6. OVERVIEW OF UNMANNED AERIAL VEHICLE SYSTEMS

7. HISTORICAL DEVELOPMENT

8. TYPES & TECHNOLOGIES

9. MODERN TRENDS

10. 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.

10.1 Relevant Institutions

10.1.1 European Union Aviation Safety Agency (EASA)

The European Union Aviation Safety Agency (EASA) [1] plays a crucial role in harmonizing aviation safety standards across all EU member states. Its primary objective is to maintain a consistent and high level of safety in civil aviation operations throughout the European Union. EASA achieves this through the establishment and enforcement of common regulations applicable to all member states. Notably, for the standardization of Unmanned Aerial Systems (UAS), EASA has implemented Regulations (EU) 2019/947 [2] and (EU) 2019/945 [3].

10.1.2 Spanish Aviation Safety and Security Agency (AESA)

In Spain, the Spanish Aviation Safety and Security Agency (AESA) [4] 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.

10.2 Applicable Legislation

10.2.1 Implementing Regulation (EU) 2019/947

The Implementing Regulation (EU) 2019/947 [2] establishes the operational rules and requirements for UAS within the European Union. 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 [3] 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 [5], 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.

10.2.2 Delegated Regulation (EU) 2019/945

The Delegated Regulation (EU) 2019/945 [3] defines the rules and standards for UAS within the European Union. 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.

10.2.3 Regulation (EU) 2024/1689: Artificial Intelligence Act

The Artificial Intelligence Act (AI Act) of the European Union [6], which came into force on the 1st of August 2024, aims to ensure that AI systems are safe, transparent, and ethical, while fostering innovation and protecting fundamental rights as stated in the Delegated Regulation (EU) 2024/1689 [7]. The 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.

10.3 Operational Categories

The Regulation (EU) 2019/947 [2] classifies UAS into three distinct operational 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 Visual Line of Sight). 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 Scenarios (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

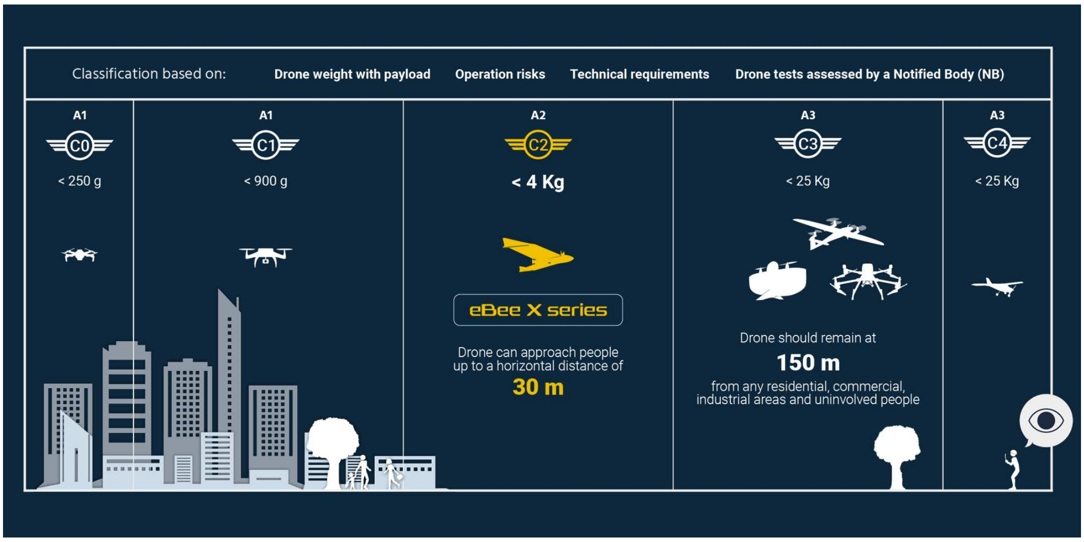

Figure 10.1. *EU Regulations Open Category chart describing the subcategories A1, A2, and A3 with their respective operational limitations extracted from [8]*

procedures similar to those for commercial air transport.

10.3.1 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 Maximum Takeoff Weight (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.

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 Visual Line of Sight (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 III

Methodology

11. REQUIREMENTS

Based on careful analysis of the conclusions from the current trends in UAVs outlined in chapter 9 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.

11.1 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 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 European Union regulations. See chapter 10 for more information.

11.2 UAV 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.

11.3 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.

11.4 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.

12. DESIGN

13. IMPLEMENTATION

Part IV

Results

Part V

Conclusions

14. CONCLUSIONS

15. FUTURE WORKS

16. SOCIO-ECONOMIC ENVIRONMENT

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