INGENIA SE | COURSE 2022-2023

OpsCon (Final)

Hell-ix Team

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Contents

1. Scope

1.1 General

The purpose of this project is to design and implement an autonomous drone racing system in order to create an exciting and competitive race between two different teams. The teams will design their own autonomous drone to make it navigate through a series of obstacles. The winner team will be the one who performs better in the competition. This project will require the utilization of various technologies, including software to program the system and drone hardware. In addition, obstacles design, race management software and safety measures will be required in order to ensure the the success and safety of the project.

1.2 Identification

This project is being carried on by two different teams of engineers who will study and prepare the required knowledge to design the racing system together but designing their own drone independently. Both teams are composed by twelve engineers who are specialized in different fields such as drone design and construction, software development and programming, obstacle design and sustainability and environment management. Both teams are organized in small groups (between 2 and 5 people) which will manage a different field to maximise their efficiency and performance.

1.3 Document overview

This OpsCon document provides a detailed description of the autonomous racing drone system, including its prototypes and alternatives as well as the final selected drone specifications. This document is intended for use by the project team, stakeholders, and anyone involved in the operation of the system. The document includes detailed information on the competition and stages of development.

1.4 System overview

The drone racing system is formed by three main components, including the two drones themselves, the competition management and design, which includes the race, the obstacle and the scoring setting, and finally the software and programs management.

2. Stakeholders

Stakeholders can be defined as all those people or organizations affected by the actions of a company or, in this case, a team. It is especially important to consider which stakeholders will be involved throughout the entire process during the making of the OpsCon and to properly recognize their needs. The main reason about this is the influence that they will have over the system. This influence can be positive or negative, at different stages of time, so identifying them beforehand will help us to be prepared to avoid possible issues.

The following list shows some of the most important stakeholders in this project. It is important to clarify the non-definitive character of this list, being very likely that it will evolve, and new stakeholders will be incorporated throughout the project.

2.1 Suppliers

They are in charge of delivering the drone to the team, as well as the different required materials and the needed accessories that will be installed. They mainly influence the construction and testing stages due to possible delays in delivery. The suppliers will need to keep weekly or even daily conversations with the project team in order to stay informed and ensure that the delivers meet the specifications, such as quality and time. In particular, the main hardware supplier is the swedish company Bitcraze.

2.2 Government (European, Spanish and Madrid)

They limit the conditions of the project by imposing laws. As it was studied during the law investigation, there are two main laws that affect this project: the *Commission Implementing Regulation (EU) 2020/746* and the *Commission Delegated Regulation (EU) 2019/945*. They influence the initial stages of the project, in aspects such as the location of the competition or the weight of the drone. The Government needs to be informed about the laws project compliance.

2.3 Competition management team

In this case, for practical purposes, the other team has been considered as a stakeholder, as it will limit some aspects related to the competition tests and the drone specifications. They influence primary stages, setting conditions of the competition. The competition teams need to be informed about the goals in order to adapt and prepare for the different situations and achieve the objective of the project.

2.4 Rival team

It is the only competitor. They force the opposite project team to anticipate the specifications of the rival drone in order to try to beat them in the competition. They influence the entire course of the project. The rival team needs to know the rules and specifications of the drone and the race in order to adjust its project and work to the stablished guidelines.

2.5 Escuela Técnica Superior de Ingenieros Industriales

They are in charge of supplying the team with facilities to test and carry out the competition, as well as financing it. They influence during the entire course of the project. They need to be informed about the project needs in order to provide both teams the necessary equipment, space and facilities to help the teams to succeed with the project.

2.6 Teaching team

They instruct and advise the different teams on macro level knowledge, such as the functioning of an organization or system, and on micro level, programming oriented to autonomous drones. They are influential throughout the course of the project. In addition, they need the students to attend the courses and preparation classes to help them with the project development and responding to their questions and doubts.

2.7 CVAR team

A reliable and experienced source of advice on the subject of autonomous drones. It influences punctually, depending on the needs of the team, but throughout the course of the project. They can provide some technology to make some testing. However, they are a punctual support, so they need to know in advance when the team will require their help.

3. Autonomous Racing Drone

In this project we intend to work with an autonomous drone. Therefore, it is not intended to design a drone with great technical qualities, but a drone that performs a series of basic tasks and is capable of achieving a simple mission, autonomously. Taking into account the above, the use of three possible drones for the competition has been discussed. These drones are Crazyflie, Ryze Tello and a custom drone made by the team from scratch.

3.1 Crazyflie

Crazyflie is a 27 grams drone that offers a wide range of possibilities to make it autonomous. Several sensors are already included in Crazyflie, like a three-axis accelerometer or a pressure sensor. It is 9 cm long, its battery is supposed to last up to 7 minutes, and its charging time is about 40 minutes. It can reach a fly speed of up to 5 m/s. This is the chosen drone for the competition. In the next section further information can be found.

3.2 Ryze Tello

Ryze Tello is a heavier drone (it weighs about 80 grams) than Crazyflie, but it's a bit bigger. It has a 720p video camera onboard with an electronic stabilization system to record stable videos. It also has a LED, Wi-Fi connection, and it can reach 10 m/s while flying human-controlled. Yet, making it fly autonomously may reduce its speed due to its limited data processing capabilities. The drone can fly up to 13 minutes.

3.3 Custom Drone

Despite building a drone from scratch is an exciting project, it is not a possibility for this project because of various reasons. First, a drone made in this way is usually large in size, because it is necessary to install the different pieces, wires and sensors. As its size increases, its weight increases, and if it exceeds the weight limited by law, 250 grams in this case, one of the team members must obtain a license to pilot the drone.

The last parameter that is important to talk about is the cost of this type of drones. Obtaining the license mentioned above costs more than €400, and buying all the parts separately is also quite expensive, reaching prices of up to €800-€2.000.

3.4 Comparative

In order to perform the selection of the most appropriate drone for the system, all the previously commented are taken into account. The following table collects the principal characteristics of each drone.

Table 3.1: Drone Comparative

Drone	Weight	Speed	Battery	Price	Special Features
Crazyflie	27 g	5 m/s	7 min	600 €	Wide range of possibilities.
Ryze Tello	80 g	10 m/s	13 min	109 €	Cheap. No hardware modification.
Custom Drone	≥ 250 g	-	-	≥ 800 €	Drone driving license essential.

After taking a quick look at each drone and discussing the pros and cons of each one, the Crazyflie drone is selected due to its modifications capabilities, despite its price. The Ryze Tello is a good option too but its limitations were the reason for its rejection. The custom drone was discarded because of its weight, as it is mentioned above.

3.5 Specifications of the Crazyflie drone

This is the drone which has been chosen for the competition. This drone meets the characteristics required for this project. First of all, it is not a very complex drone to use nor excessively expensive.

Crazyflie can be improved with additional decks. This capacity gives the Crazyflie extra abilities in positioning, visualization and sensing. There is a broad range of decks available to customize the drone. Furthermore, the platform allows to create and add custom decks. This enables the user to utilize customized sensors and other devices on the platform. Communication buses and GPIO pins are exposed by the expansion bus to be used by decks as required.

3.5.1 Hardware

In terms of hardware components, the Crazyflie is composed of many different components. These have all their specific skills and functionalities. The microprocessors are the most important components of the Crazyflie : the STM32F4 controls the main Crazyflie firmware with all the low-level and high-level controls, and the NRF51822 manages the power control and all the radio communication.

In order to control the Crazyflie flight, a mobile device or a computer are needed. A mobile device is the best option to get quickly into the air. In the other hand, piloting skills are required. A computer offers more options and greater control but it requires two things : A standard gamepad for maneuvering, and a Crazyradio PA for communication. In this project, a computer will be the chosen tool by using the Crazyradio PA.

3.5.2 Control

There are different options on how to run the computer. The first one, a virtual machine. The second one, Operating Systems as Windows/Mac/Linux. For the virtual machine, there is a virtual machine (VM) created to get the drone into the air as quickly as possible. This VM has pre-installed all the needed software for flight and development.

This way it is the chosen one by the team to control the drone using a computer. All the required steps to be successful in the installation of the VM are detailed in the official Crazyflie's website.

3.5.3 Drone Vision

To identify an obstacle and execute the corresponding movement, it is necessary to use image processing software and a camera installed on the drone. OpenCV is the huge open-source library for the computer vision, machine learning, and image processing. It has C++, C, Python and Java interfaces and supports Windows, Linux, Mac OS, iOS and Android.

This tool can be used to process the images taken by the drone. Depending on the camera selected, it will be able to separate colors, identify shapes and calculate areas of the photo. With this information the drone´s computer is able to know which obstacle is in front of it, how far away is it and how to avoid it.

4. The Competition

The competition will be divided into a total of 3 challenges and 2 preliminary tests. The first preliminary tests are done in order to ensure the correct functioning of the drone, and they won't contribute any winning points. The challenges that follow will be scored. Finally, the winning team will be the one that has obtained the most points in the 3 challenges and will be crowned as the champion of the competition.

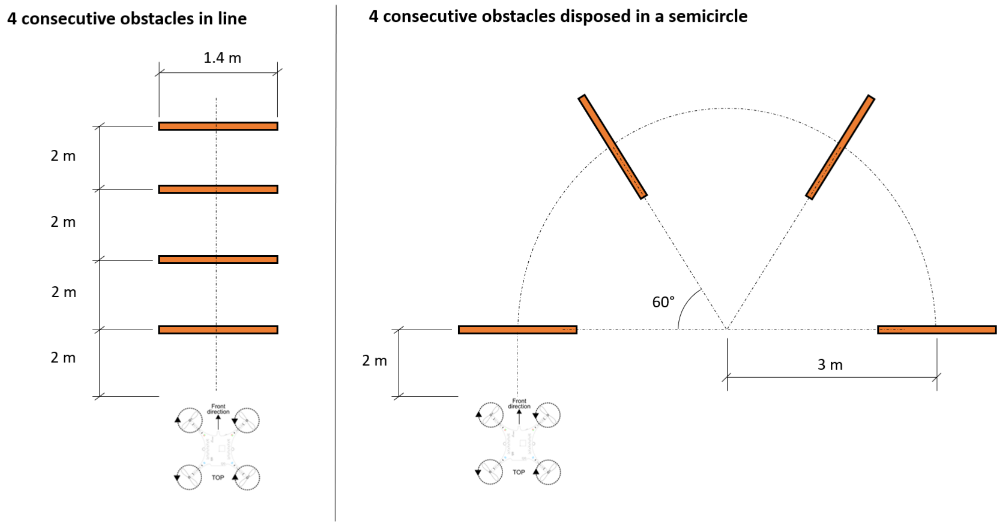
4.1 Test

The two preliminary tests are as it follows:

- **Flight test:** The drones must travel a predefined distance in a straight line. This test is conducted to ensure that the drone can take off, fly, and land successfully.
- **One obstacle test:** The drone must traverse a single obstacle placed in front of it. This test is conducted to ensure that the drone can navigate a single obstacle without crashing or exhibiting unplanned behavior.

Once the preliminary tests are completed successfully by both teams, the challenges will begin. The three challenges are as it follows:

- **4 consecutive obstacles in line:** The drone must traverse 4 obstacles placed in a straight line, in front of the drone. The distance between them will be 2 meters. See the diagram below for a visual explanation.
- **4 consecutive obstacles disposed in a semicircle:** The drone must traverse 4 obstacles placed forming a semicircle. The radius of the semicircle that conform the disposition of the gates will be 3 m. The angle between two gates with respect to the center of the semicircle will be 60°. See the diagram below for a visual explanation.
- **Freestyle challenge:** For 1 minute, the drone must perform a series of maneuvers to impress the audience. The creativity of the performance will be positively taken into account.



The regulations stipulated for the drone, tests and challenges are specified below.

4.2 Regulations

4.2.1 Drone regulations

- The maximum weight allowed for each drone will be 100 g, including all the necessary components and accessories for its correct operation.
- The computing mode will be at the choice of each team.
- Each team must have a minimum of three batteries for the drone, allowing it to complete all tests without interruptions. If more batteries are needed, the team must have them before the competition.
- Teams must present their drones for inspection before the start of the competition. If any drone does not comply with the established regulations, the team will be disqualified.
- During the competition, teams must follow the instructions of the security and event organization staff at all times.
- In the event of any incident during the competition, the responsible team will be disqualified and must pay for any damages caused.

4.2.2 Test regulations

Speed test:

- The two drones will do it separately.
- The drone will fly in a straight line, maintaining a minimum distance of 5 meters between them and the limits of the enclosure.
- The distance of the flight will be from 10 to 15 meters. Final distance will be decided during the competition.
- Take-off will take place when the starting signal is given, which will consist of a horn

sound.

- If a drone takes off before the starting signal, it will be disqualified from the test.
- Drones must be able to brake to avoid colliding with the end of the pavilion. Contestants will take into account the length of the pavilion.
- After braking, the drones must land.

One obstacle test:

- The two drones will do it separately.
- The drone will take off when the starting signal is given, which will consist of a honking sound.
- If a drone takes off before the starting signal, it will be disqualified from the test.
- The drone must traverse the obstacle without crashing nor exhibiting unexpected behaviour.
- If a collision occurs between the drone and the obstacle or exhibit unexpected behaviour, it will be disqualified from the test.
- The drone must be able to brake after traversing the obstacle.
- After braking, the drone must land.

4 consecutive obstacles in line challenge:

- The two drones will do it separately.
- The drone will take off when the starting signal is given, which will consist of a honking sound.
- If a drone takes off before the starting signal, it will be disqualified from the test.
- The drone must traverse the 4 obstacles without crashing nor exhibiting unexpected behaviour.
- If a collision occurs between the drone and one of the obstacles or exhibit unexpected behaviour, the scoring will be lower. See chapter 4.3 for detailed scoring system.
- The drone must be able to brake after traversing the 4 obstacles.
- After braking, the drone must land.
- The entire course must be completed in less than 4 minutes.

4 consecutive obstacles in a circle challenge:

- The two drones will do it separately.
- The drone will take off when the starting signal is given, which will consist of a honking sound.
- If a drone takes off before the starting signal, it will be disqualified from the test.

- The drone must traverse the 4 obstacles without crashing nor exhibiting unexpected behaviour.
- If a collision occurs between the drone and one of the obstacles or exhibit unexpected behaviour, the scoring will be lower. See chapter 4.3 for detailed scoring system.
- The drone must be able to brake after traversing the 4 obstacles.
- After braking, the drone must land.
- The entire course must be completed in less than 4 minutes.

Obstacles:

- Gates: The drone must pass through the center of a square gate measuring 1.4x1.4 meter, raised with the bottom base half a meter off the ground.
- There will be one judge at each obstacle to ensure that the rules are followed. If a drone does not comply with a rule or regulation, it will be disqualified from the test.

Freestyle challenge:

- The two drones will do it separately.
- The drone will take off when the starting signal is given, which will consist of a honking sound.
- If a drone takes off before the starting signal, it will be disqualified from the test.
- The drone must land successfully 1 minute after the initial horn sound.

4.3 Scoring for each test

4 consecutive obstacles in line challenge:

- The winning drone will be the one to traverse all 4 obstacles and to land successfully in the lowest time.
- If none of the drones succeed, the winning drone will be the one that successfully traversed the most amount of obstacles.

4 consecutive obstacles in a circle challenge:

- The winning drone will be the one to traverse all 4 obstacles and to land successfully in the lowest time.
- If none of the drones succeed, the winning drone will be the one that successfully traversed the most amount of obstacles.

Freestyle challenge:

- The point will be decided by the audience.

5. Operational scenarios

This section describes potential scenarios that may occur during the drone racing development. Two scenarios are presented: Test Scenario and Emergency Scenario.

5.1 Test Scenario

To conduct safe indoor autonomous drone flight tests, the following conditions of the test scenario must be considered:

- **Spacious area:** The test area must be spacious enough to allow the drone to fly without obstacles and without the risk of collisions with nearby walls or ceilings.
- **Adequate lightning:** Lighting in the test area should be adequate to allow for drone visibility and ensure good quality of captured images and data.
- **Abscence of obstacles:** The test area should be free of obstacles that may damage the drone or interfere with its flight, this condition is not related with the competition-specific obstacles that the drone will have to overcome in the race.
- **Air traffic control system:** If there are other drones or flying vehicles in the test area, an air traffic control system should be available to coordinate and control air traffic in the area.
- **Communication system:** It is important to have a secure and stable communication system for real-time drone control and for the transmission of data and telemetry.
- **Network security:** The communication network should be secured against interruptions or signal loss.
- **Safety equipment:** It is important to have appropriate safety equipment in the test area to prevent accidents and protect people who are present in the test area.
- **Regulatory compliance:** It is important to ensure compliance with all applicable local or national laws and regulations for conducting autonomous drone tests. Also, its necessary to have the permissions of the ETSII to be able to test in their facilities.

In general, the main goal of creating a test scenario for autonomous drones in indoor spaces is to ensure the safety of people, the drone, and the test space itself. Therefore, it is essential to consider all relevant aspects and take appropriate measures to minimize potential risks associated with autonomous drone flight in closed spaces.

5.2 Tests Description

In this chapter, a suggested set of tests for the drone to be completed successfully before its participation in the competition will be listed and explained. The tests are ordered in a specific way, so the team may check that these tests are made in this order to make sure that the drone is ready for the competition.

If there are changes in the drone hardware or configuration, the participants should consider repeating the tests in order to ensure the correct functioning of drone for the competition. The following list represents the sequence of tests that the drone might perform, in chronological order:

- **Stability and control test:** The drone should be subjected to an initial stability and control test, to verify that it can stay in the air without excessive vibrations and can properly respond to controller commands. This test may include basic maneuvers such as ascent, descent, turns, and lateral movement.
- **Obstacle detection test:** Next, the drone's ability to detect obstacles using computer vision techniques should be tested. This could be done by placing static objects in the drone's environment and measuring its ability to detect and safely avoid them.
- **Speed and acceleration test:** Once the drone's ability to maintain stability and detect obstacles has been verified, its speed and acceleration should be tested on a test circuit. The drone should be able to reach competitive speeds and accelerate and brake safely and efficiently.
- **Battery and autonomy test:** Once the drone's ability to compete in speed and avoid obstacles has been verified, its battery autonomy should be tested. The drone should be able to complete a full race without running out of battery.
- **Programming and software test:** In this test, the drone's ability to execute all tasks required during the race, including obstacle detection and flight control, would be evaluated. Simulation tests could be performed to assess the drone's ability to navigate different race situations.
- **Safety test:** In this test, the drone's ability to comply with the safety regulations required to participate in a race would be evaluated, ensuring that it does not pose a risk to spectators or other competitors during the race.

5.3 Emergency Scenarios

During the drone competition or tests, it is necessary to consider possible situations in which the drone stops responding to programmed commands or even manual commands. Therefore, the following guidelines for action and implementation have been established:

5.3.1 Emergency Scenario 1: Drone stops when changing direction

Possible reasons:

1. The camera has stopped working or does not recognize obstacles well.
2. Programming code failure.
3. Hardware failure: motor controllers have lost connection with the CPU.

Procedure for action:

1. Use the remote control to manually take control of the drone.
2. Restart the drone and check if it was a one-time failure.
3. If not, improve the lighting of the area and retry step 2.
4. If it still does not work, check the code and look for programming or hardware failures.

5.3.2 Emergency Scenario 2: Loss of connection between the drone and the ground station

Possible reasons:

1. Excessive distance of the drone from the ground station.
2. Failure in the network unit of the ground station or the drone.
3. Programming code failure.

Procedure for action:

1. Use the remote control to manually take control of the drone.
2. Bring the drone closer to the ground station.
3. If step 2 does not work, restart the drone and check if it was a one-time failure.
4. If step 3 does not work, check the code and look for programming or hardware failures.

5.3.3 Emergency Scenario 3: Loss of control of the drone with the remote control.

Possible reasons:

1. Lack of batteries in the remote control.
2. Disabling of some commands when changing the code of the control unit.
3. Failure in the drone's antenna.

Procedure for action:

1. Immediate shutdown of the drone from the ground station.
2. Factory reset of the drone code.
3. If it works, check the programming code.
4. If it doesn't work, check the drone's hardware components.

5.3.4 Emergency Scenario 4: Short circuit of the drone in operation.

Possible reasons:

1. Voltage overload due to poor code implementation.
2. Spillage of any liquid on the drone.
3. Drone hit with an element that has caused physical damage.

Procedure for action:

1. Completely disconnect the drone from the battery.
2. Check the damage to the drone.

3. Check for possible moisture in the drone.
4. If it is still operational, restart at factory levels and check for correct operation.
5. If it works, review the programming code and test again.

6. Summary of impacts

The project to create an autonomous racing drone involves several technical and logistic challenges, as well as the collaboration of multidisciplinary teams of university students, university infrastructure and support.

In this context, it is important to identify and assess the operational, organizational impacts that may arise as the construction and operation of the drone progresses. In addition, it is necessary to assess impacts that may occur while the project is ongoing.

This section aims to provide a detailed description of potential impacts and their assessment in order to help project teams anticipate and appropriately manage the risks and opportunities associated with the creation of an autonomous racing drone. By considering these impacts and establishing appropriate measures to address them, the creation of a safe, effective, and sustainable autonomous racing drone can be ensured.

6.1 Operational Impacts

Operational impacts refer to the effects that the creation and operation of the drone may have on its environment and the users of the system. Below are some of the potential operational impacts that should be considered:

- **Safety risks:** The operation of an autonomous racing drone involves certain safety risks both for those in charge of building and testing the drone, as well as for spectators and staff participating in the final event. Therefore, it is necessary to conduct a thorough risk analysis and establish appropriate safety measures to minimize the risks associated with the operation of the drone.

- **Impact on the environment:** The different tests where the operation of the drone is tested, and the final run, may have impacts on the environment and the people in it, especially in terms of noise. Measures should be taken to minimize these impacts, such as choosing a suitable location for the race and a time slot in which the race will not disturb university staff and students.

- **Maintenance and operational requirements:** The autonomous racing drone will require proper maintenance and operation to ensure its correct functioning. This implies an investment of time and resources to carry out the necessary maintenance and operation tasks.

6.2 Organizational Impacts

Organizational impacts refer to the effects that the creation and operation of the drone may have on the individuals and teams involved in the project, as well as on the university supporting the project. Some of the possible organizational impacts are:

- **Need for training and capacity building:** The creation and operation of an autonomous racing drone requires specific technical skills and knowledge. The student teams involved in the project may need additional training and education to develop and operate the drone.

- **Resource allocation:** The construction and operation of the autonomous racing drone will require the allocation of adequate resources, including time and budget. Proper planning and allocation of available resources is important to ensure the success of the project.

- **Coordination between teams and departments:** The project to create an autonomous racing drone involves the collaboration of multidisciplinary teams of students and university staff. It is important to establish good coordination between the teams and departments involved to ensure effective communication and collaboration, and to avoid duplication of efforts.

6.3 Impacts during project development

Impacts during project development refer to the effects that may arise during the different phases of the project, from planning to implementation. The following are some of the possible impacts that may occur during project development:

- **Changes in project requirements and objectives:** As the project progresses, changes in project requirements and objectives may arise. It is important to take these changes into account and adjust plans and strategies accordingly.

- **Integration and compatibility issues:** The autonomous racing drone is composed of different components and technologies, and it is important to ensure proper compatibility and integration between them. Proper planning and rigorous testing must be carried out to ensure the correct functioning of the drone.

- **Tight timelines and budgets:** The project to create an autonomous racing drone can have tight timelines and budgets. It is important to take these factors into account and carry out proper planning and management to ensure that the project is delivered on time and on budget.

7. Analysis of the proposed system

Subsequently, a brief analysis will be presented regarding the proposed autonomous drone racing system, with comparisons drawn between this system and a human-piloted drone racing system.

7.1 General

The autonomous drone racing system involves a Crazyflie drone (Hell-ix team) and a DJI Ryze Tello drone (Droning team), competing in a speed race where they must avoid obstacles using a camera built into the drones. The drones will use real-time image recognition code to identify shapes and make decisions accordingly.

7.2 Benefits

Using autonomous drones for the race has several advantages, both technically and in terms of safety:

- The use of autonomous drones can make racing safer by eliminating the need for human pilots and, with it, the potential for human error in piloting.
- The use of autonomous drones is more efficient than the use of human-controlled drones, as they can react faster and with greater precision to changes in the environment.
- The real-time image recognition code allows for quick and accurate obstacle avoidance.
- The use of cameras as sensors is a cost-effective solution compared to more complex sensor systems.

7.3 Disadvantages and limitations

- The accuracy of obstacle detection and avoidance can be affected by factors such as lighting conditions and the quality of the camera.
- There is a risk of technical failures or malfunctions, such as a drone losing its connection or running out of battery. Also, there is a possibility of programming code failure, causing the drone not to function correctly, putting spectators in danger.
- Autonomous drone racing is still a relatively new field, and there may be limitations in terms of available technology and regulations.
- The use of image recognition technology can be limited by the complexity of the environment and the variability of obstacles.

7.4 Alternatives considered

In addition to the alternatives considered regarding the drone selection, which will not be mentioned again to avoid redundancy, other possible alternatives were taken into account at the hardware and software level:

- The use of a ground station or, on the contrary, using only on-board processing, with the latter option limiting the operational capacity of the drone but allowing for a greater flight distance without possible interference with the station.
- The type of image recognition, which can be through QR codes, shapes, and colors... Although the QR code system is widely used and studied, we believe that the reading speed of such a code would slow down the race.
- The programming language to be used, considering Python, C, C++, a combination of several...
- The use of multiple sensors, such as LiDAR or ultrasonic sensors, in addition to the camera, can improve the accuracy of obstacle detection and avoidance.
- Human pilots could also be used in conjunction with autonomous systems to provide additional control and guidance.

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