TÉCNICO LISBOA

SENTINEL

Anti-Drone Detection for Communication Jamming System for Security Forces

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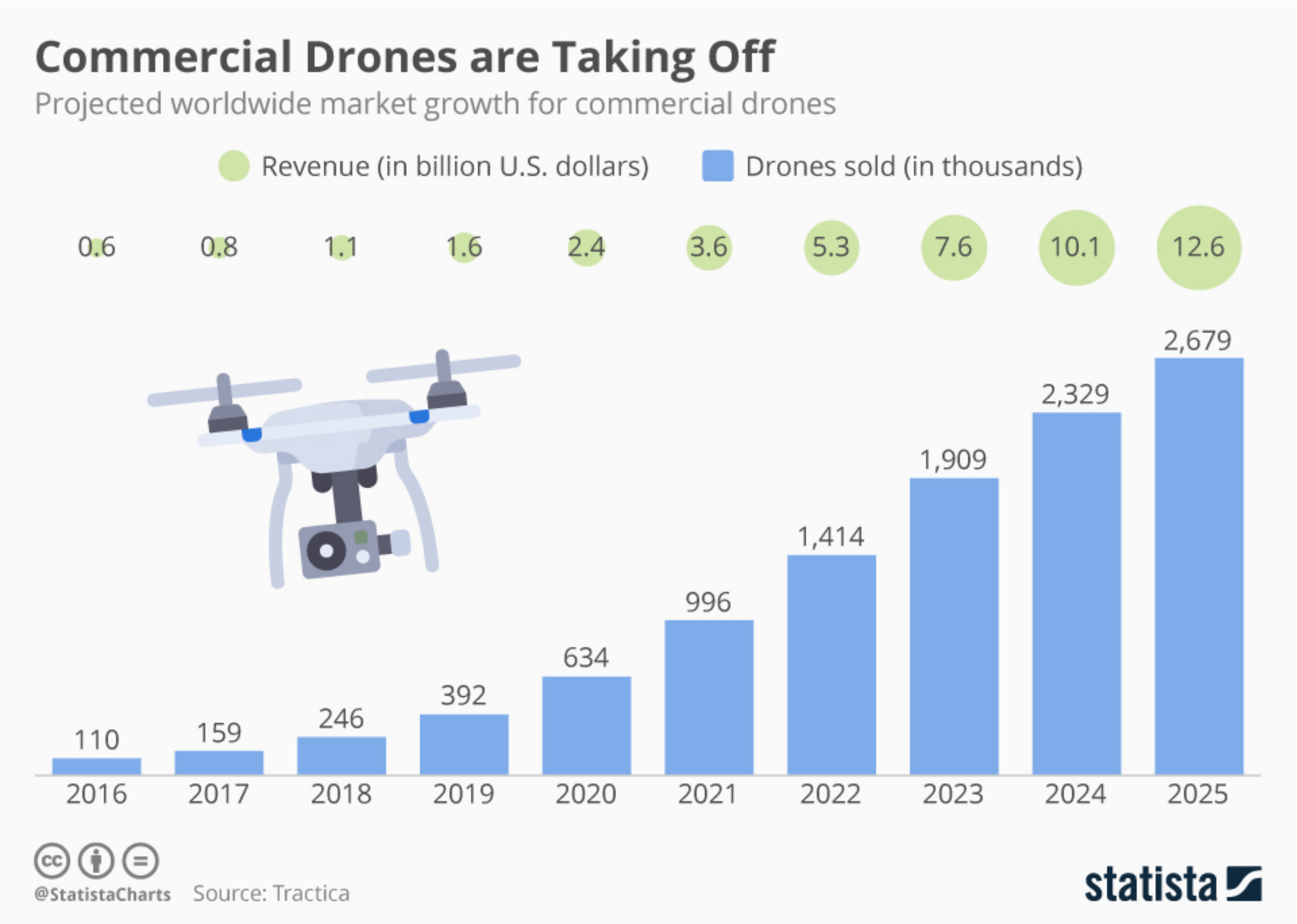
MEET THE TEAM

Guilherme Martins 106274	Afonso de Mello 107495	Guilherme Luís 106755
Team Leader/Project Manager	R&D Enginner	Systems Analyst
Francisco Rodrigues 106695	João Firmino 107485	Rodrigo Sanguino 84342
Technical Lead	Software Developer	Embedded Systems Engineer

1. ADVISORS AND MENTOR

- Scientific Advisor: Tenente Coronel João Boita
- Scientific Co-advisor: Major Machado; Major Pagaimo
- Coordinator: Prof. João Felício
- Co-coordinator: Prof. Emmanuel Cruzeiro
- Mentor: Prof. João Gonçalves

2. PROBLEM DEFINITION

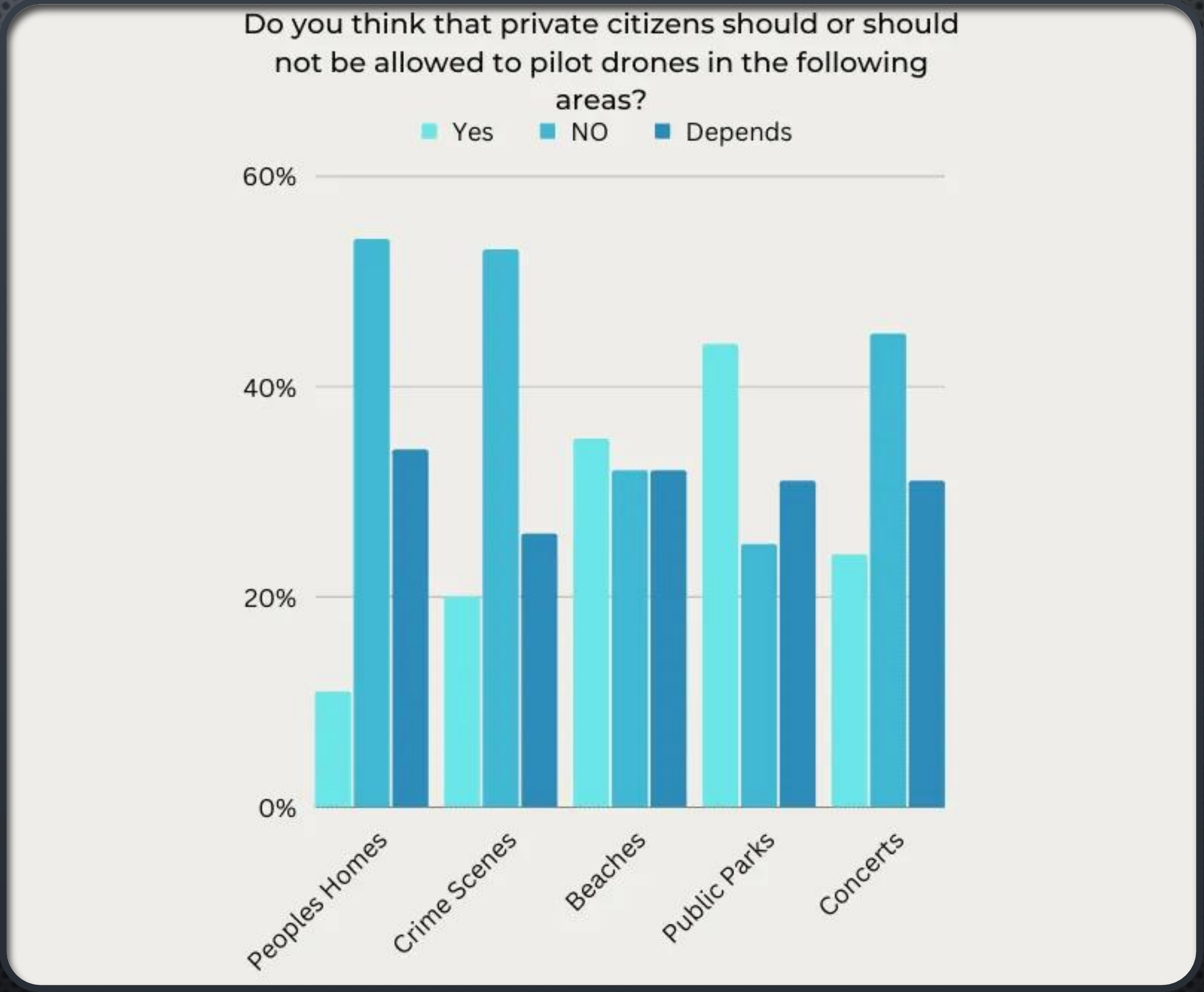


GROWTH OF DRONE USAGE

Drones have gained widespread use for a variety of applications, from recreational flying to industrial uses like surveillance, monitoring, and package delivery.

UNAUTHORIZED SURVEILLANCE OF PRIVATE AREAS

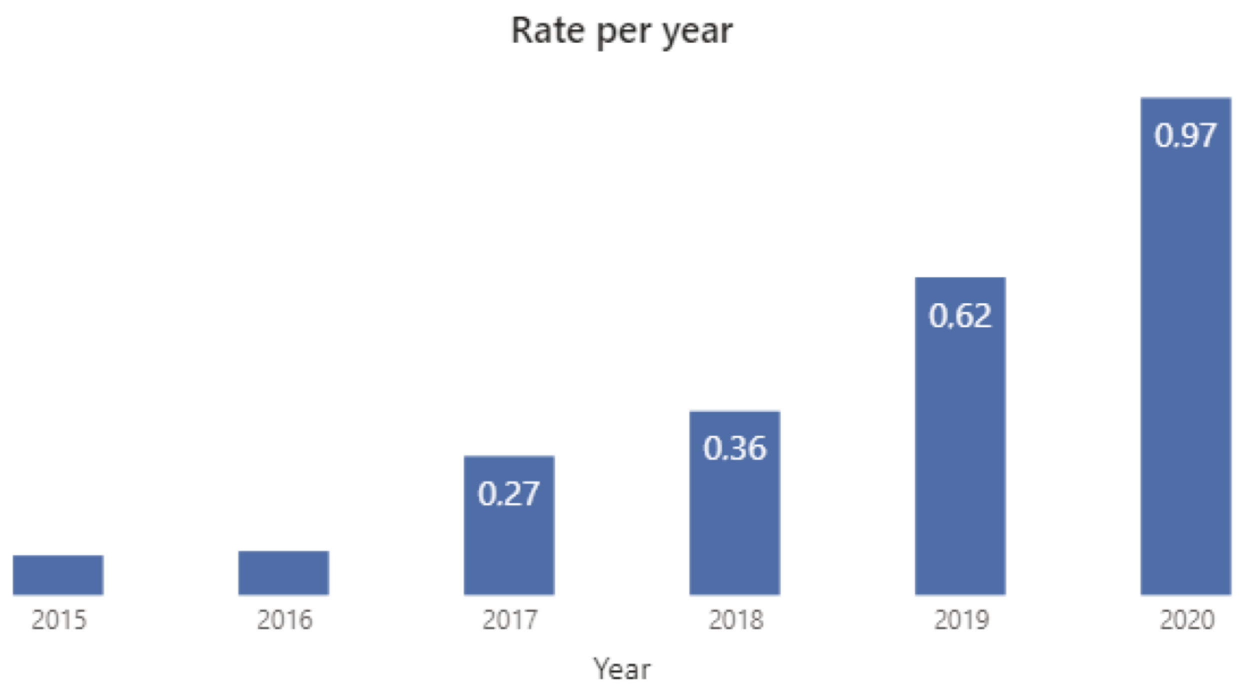
Drones increasing use has also led to significant security concerns. Unauthorized drones, especially those used for illegal surveillance or nefarious purposes, pose a threat to privacy, security, and public safety.



DRONE INTRUSIONS AND SECURITY THREATS

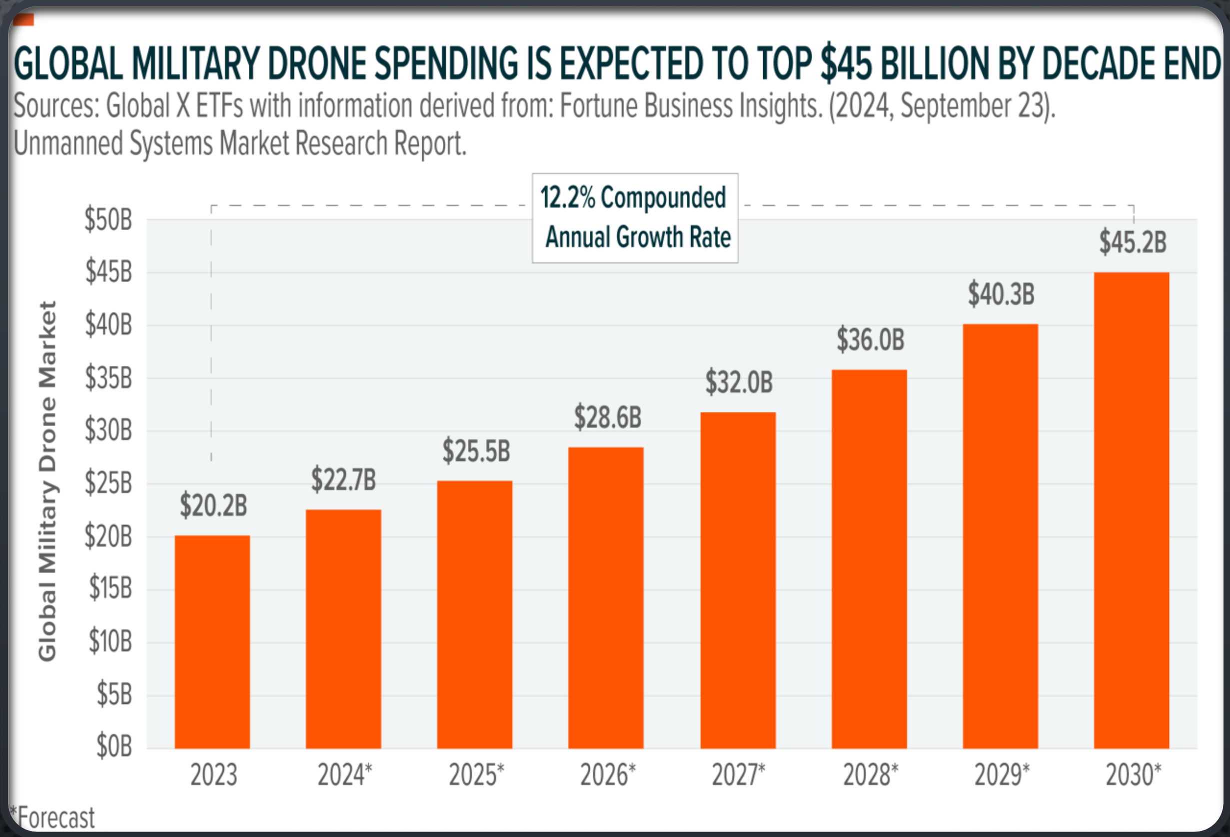
Security forces are often ill-equipped to detect and neutralize these unmanned aerial vehicles (UAVs), which can be difficult to track due to their small size, mobility, and the use of secure communication channels. This makes it challenging to prevent potential risks such as espionage, smuggling, or even terrorist attacks.

Yearly number of drone intrusion in Italian airports per 10,000 airport movements.



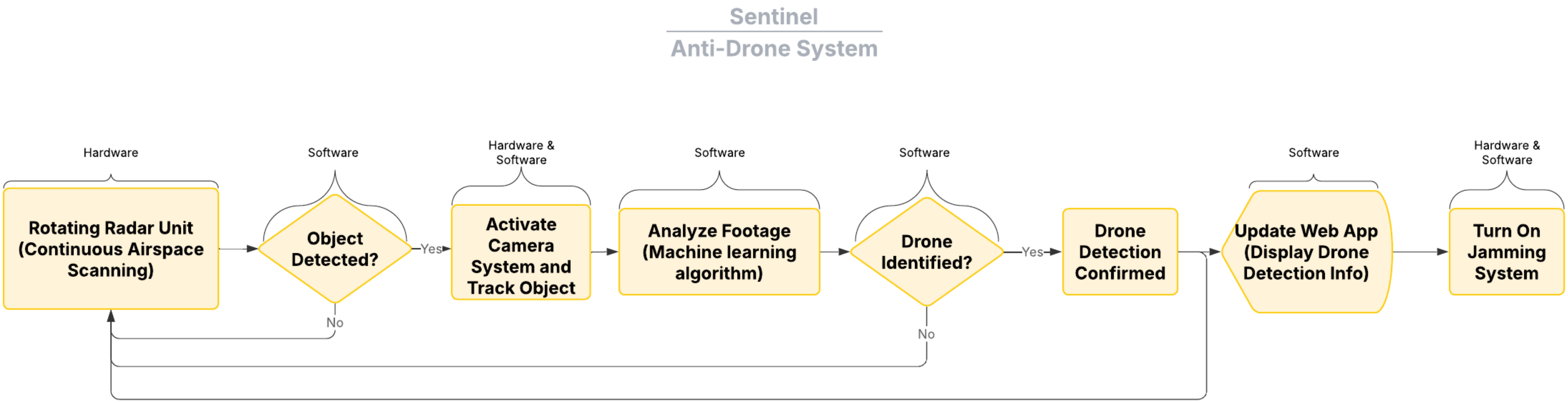
2. PROBLEM DEFINITION

The challenge is to develop an innovative system that allows security agencies to detect the presence of unauthorized drones in restricted or sensitive areas. Additionally, the system must be capable of directing interfering signals with the drone's communication signals, particularly radio-frequency signals, to prevent the drone from transmitting or receiving control commands. This would enable security forces to gain control of the situation and mitigate the potential threat posed by rogue drones. A system that effectively combines detection, tracking, and jamming technologies could be a game-changer in improving national and public security efforts.



PROJECT OBJECTIVES

- Detect unauthorized drones using radars, computer vision and machine learning
- Implement a real-time monitoring and alert platform
- Develop and test jamming techniques for drone neutralization
- Integrate multiple sensors to enhance detection accuracy (acoustic sensors)
- Ensure system adaptability for various security scenarios



PROJECT OBJECTIVES

3. SOLUTION BENEFICIARIES

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Security Agencies

Security forces, military personnel, and border control entities that need to protect restricted or high-risk areas against drone incursions

3. SOLUTION BENEFICIARIES

Governmental institutions

Authorities responsible for overseeing national security, airports, government buildings, and sensitive locations

3. SOLUTION BENEFICIARIES

Private Sector

Organizations and industries concerned with protecting infrastructure, assets, and sensitive data from unauthorized aerial surveillance

THALES

GRUPO EULEN

TEKEVER

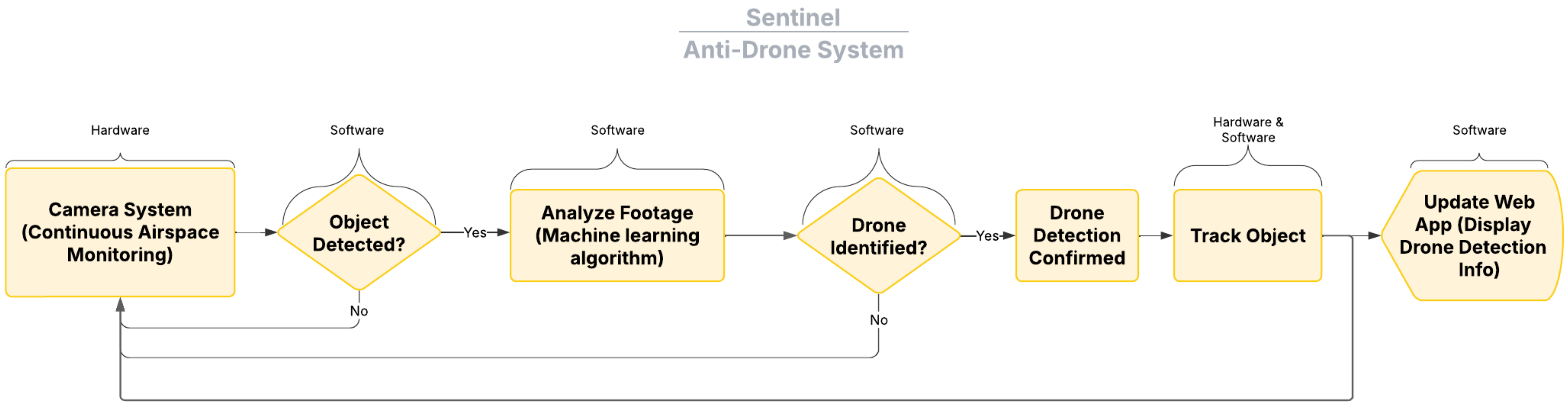
Connect Robotics

SwAtter

4. TECHNOLOGICAL SOLUTION

Drone Detection Systems: Optical sensors (such as cameras and infrared systems), radar, acoustic sensors and Rf Receivers to visually detect and track drones.

Machine Learning Algorithms: To distinguish drones from other flying objects, such as birds, based on detected video.



4. TECHNOLOGICAL SOLUTION

5. COMPETITORS AND PREVIOUS WORK

Currently, several solutions exist, including manual drone detection using radar systems, acoustic sensors, and optical cameras. Some systems attempt to jam the communication signals of drones, using RF (radio-frequency) jamming to disrupt their control and navigation. However, these solutions tend to have limitations, including short detection ranges, difficulty in distinguishing between authorized and unauthorized drones, and challenges in legally operating RF jammers due to regulatory restrictions in many countries. Some anti-drone solutions also require significant infrastructure investment and integration, making them difficult to deploy on a wide scale. While there are commercial systems available, they are typically expensive, bulky, and may not be easily adaptable to different security needs.

SOME PREVIOUS SOLUTIONS:

NQ Defense ND-BD004

Handheld Anti-Drone Jammer

AARTOS Radar Detection

Drone Radar Detection

Detection Radar IRIS

Drone Radar Detection

6. SOLUTION REQUIREMENTS

As part of this project, we decided to focus on drone detection by implementing a system based on computer vision. The core of our solution involves using a camera that will continuously rotate and track a detected drone, ensuring it remains centered in the frame. This dynamic movement is designed to facilitate future efforts in neutralizing drones by targeting their communication frequencies. Through machine learning algorithms, the system will analyze the captured images to identify and distinguish drones from other airborne objects, such as birds or civilian aircraft in real time.

To enhance usability, we will also develop a web application that allows users to monitor the system's status in real time. This platform will provide a live overview of detected objects, as well as display the total number of drones identified by the system.

If necessary, we may also explore the integration of complementary detection systems, such as radars and acoustic sensors. Additionally, if time permits, we may begin exploring potential techniques to jam the drone’s communication signals as a next step in enhancing the system’s capabilities.

6. SOLUTION REQUIREMENTS

COMPONENTS REQUIRED

- Raspberry Pi 5 8GB - Raspberry Pi SC1112

- Raspberry Pi - 12MP 76º - Raspberry Pi Camera Module 3 SC0872

- Placa HAT+ com acelerador de IA Hailo para Raspberry Pi 5 - Raspberry Pi AI HAT+ 26 ou 13 TOPS

- Motor micro servo 4.8V..6V DC SG90 - 180º

- Cartão de memória MicroSDXC 64GB classe 10 UHS-I + adaptador SD - Sandisk SDSQUAB-064G-GN6IA

- Fonte de alimentação para Raspberry Pi 5 - 27W USB-C - Branco - Raspberry Pi SC1152

COMPONENTS REQUIRED

6. Solution requirements

QUANTIDADE	ITEM	DESCRIÇÃO	FORNECEDOR	LINK	PREÇO (por und.)
1	Microcomputador Raspberry Pi 5 8GB - Raspberry Pi SC1112	Microcomputador	Mauser	https://mauser.pt/catalog/product_info.php?products_id=095-5008	90.97
1	Cartão de memória MicroSDXC 64GB classe 10 UHS-I + adaptador SD - Sandisk SDSQUAB-064G-GN6IA	Cartão de Memória 64 GB	Mauser	https://mauser.pt/catalog/product_info.php?products_id=047-4348	10.9
1	Módulo de câmara V3 oficial Raspberry Pi - 12MP 76° - Raspberry Pi Camera Module 3 SC0872	Camera para Raspberry Pi 5	Mauser	https://mauser.pt/catalog/product_info.php?products_id=095-1253	29.99
1	Placa HAT+ com acelerador de IA Hailo para Raspberry Pi 5 - Raspberry Pi AI HAT+ 26 TOPS	Acelarador para AI e Machine Learning	Mauser	https://mauser.pt/catalog/product_info.php?products_id=095-4440	129.99
1	Fonte de alimentação para Raspberry Pi 5 - 27W USB-C - Branco - Raspberry Pi SC1152	Fonte de alimentação para Raspberry Pi 5	Mauser	https://mauser.pt/catalog/product_info.php?products_id=035-4751	13.37
2	Motor micro servo 4.8V..6V DC SG90 - 180º	Rotor para rodar a camera	Mauser	https://mauser.pt/catalog/product_info.php?products_id=096-6477	3.45

7. TECHNICAL CHALLENGES

Technical challenges in a project refer to the difficulties and obstacles encountered when designing, developing, and implementing a solution. These challenges can arise from hardware limitations, software constraints, integration complexities, scalability issues, or performance optimization. Addressing them often requires innovative problem-solving, rigorous testing, and iterative improvements. Identifying and mitigating these challenges early in the development process is crucial to ensuring a successful outcome. We have identified four main technical challenges:

7. TECHNICAL CHALLENGES

Detection Range

The maximum distance at which the system can accurately detect and identify a drone in each environment. This is a crucial metric for assessing the effectiveness of the detection system

7. TECHNICAL CHALLENGES

False Positive Rate

↓

The rate at which the system incorrectly identifies non-threatening objects as drones. A lower rate indicates a more reliable and accurate detection system

7. TECHNICAL CHALLENGES

Adaptability

The system’s ability to handle different types of drones and environments and ensure it is versatile and reliable under different operational conditions

7. TECHNICAL CHALLENGES

Machine Learning Algorithm Training

↓

The main challenge in training a machine learning software to detect drones by video lies in the variability of environmental conditions, the visual similarity between drones and other flying objects, and the need for a large labeled dataset to ensure high accuracy.

8. PARTNERS

Força Aérea - Expertize

Thales - Know-How

Mauser - Components

9. TESTING AND VALIDATION METRICS

To evaluate the performance of our system, we plan to conduct tests either in a large open field or within a designated area at an Air Force facility, for which we have already obtained authorization. The testing process will be divided into five key stages, each designed to assess a critical aspect of the system's performance:

1. Detection Accuracy and False Positives Rate

In the first stage, we will introduce various objects into the detection area, including drones, birds, and other airborne elements. By analyzing the system's responses, we will verify its ability to accurately distinguish drones from non-threatening objects. To calculate the false positive rate, we will compare the number of incorrectly identified objects with the total number of objects detected during the test. This test will involve simulating realistic conditions to evaluate the system's reliability and ensure minimal false positives.

Max False Positive Rate: 25%

2. DETECTION RANGE

Next, we will conduct multiple drone flights at varying altitudes and distances to determine the maximum range at which the system can effectively detect a drone. We will document the maximum distance, measured in meters, at which the system correctly identifies the drone. This test is essential for understanding the system's operational limits and ensuring it can be deployed in diverse security scenarios.

Min Range: 2m

3. Drone Compatibility

After that, we will test the system's ability to detect different drone models. This will involve flying drones of various sizes and brands through the detection area to confirm that the system is not limited to specific models. Ensuring broad compatibility will make the system more versatile and effective in real-world applications.

9. Testing and Validation Metrics

4. Latency

A crucial aspect of our system's performance is its response time, or latency, which refers to the time it takes for the system to detect a drone after it has entered the detection area. To assess this, we will measure the time in seconds from when a drone enters the radar's line of sight until the system confirms the detection of the drone. This test will help us understand how quickly the system can react to threats and ensure that there is minimal delay between detection and confirmation, an important factor in real-time security scenarios.

Max Latency: 10s

5. Maximum Number of Drones

Finally, another key test will involve evaluating the system's ability to detect multiple drones simultaneously. In real-world applications, it is likely that multiple drones could be detected at once, and our system must be able to handle such scenarios efficiently. To test this, we will deploy two drones at the same time within the detection area and assess the system's ability to identify both drones simultaneously. This will ensure that the system remains functional and effective even in crowded airspaces, where multiple threats could be present at once.

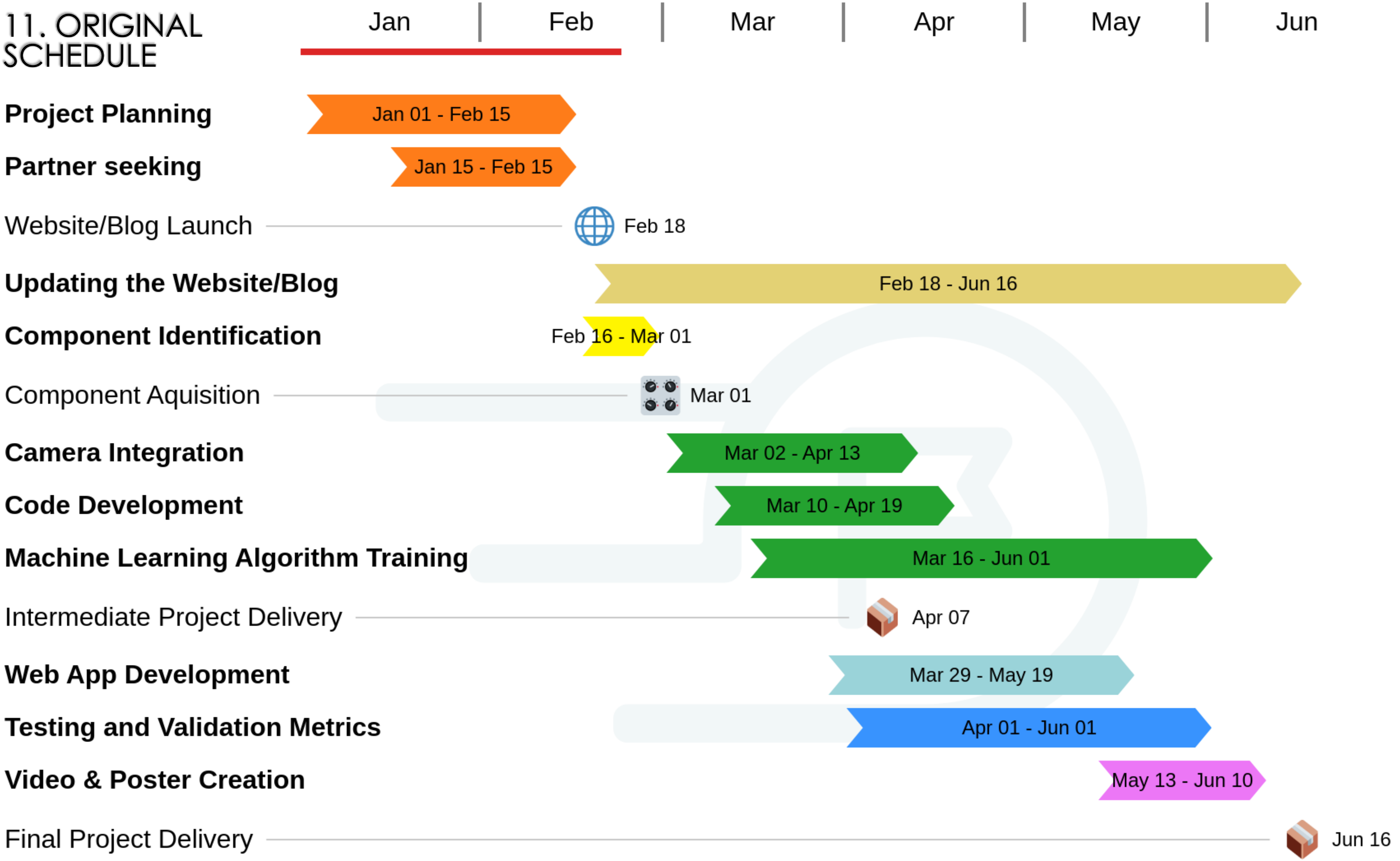
10. DIVISION OF LABOR (I)

Guilherme Martins	Francisco Rodrigues	João Firmino
Management and coordination	Research and initial Study	Research and initial Study
Engagement with Partners	Camera's Rotor Integration	Website Development
Documentation, Video and Poster making	Camera Integration	MLA Training and validation
Integration of MLA with camera rotation and Web-app		

10. DIVISION OF LABOR (II)

Afonso de Mello	Guilherme Luis	Rodrigo Sanguino
Research and initial Study	Theoretical Analysis	Research and initial Study
Engagement with Partners	Camera Rotation Code Development	Camera Rotation Code Development
Web-App Development	Finance	

11. ORIGINAL SCHEDULE



12. MID-PROGRAM STATUS UPDATE

The core goal of our project remains unchanged: developing a system for drone detection and jamming. However, we have refined our approach. Initially, we planned to use multiple fixed cameras to cover a wide field of view. Instead, we have shifted to using a single camera mounted on a movable system that can track detected drones. This approach not only simplifies the hardware setup but also opens the possibility of directing a future jamming antenna toward the target.

As a result, the system's architecture has been slightly adjusted. The prototype will now include two rotors that will allow the camera to scan the entire sky and follow a detected drone dynamically. We are currently considering the most efficient way to mount this system.

12. MID-PROGRAM STATUS UPDATE

So far, we have achieved several key milestones:

- The machine learning model has been successfully trained and validated.
- We have developed and deployed a public website and a functional web application that will displays real-time information (right now, it displays random information).
- We conducted interviews with stakeholders to better understand the user needs and refine our system.
- All the necessary hardware components have been acquired.
- We have started implementing the mechanical tracking system with the camera and rotors.

In terms of project management, we’ve assigned clear responsibilities to each team member and ensured consistent internal communication. We're now entering the hardware integration phase and continuing to iterate on both the physical and software components of the project.

13. ACHIEVED RESULTS

So far, our team has made significant progress in various aspects of the project. Below are the key achievements in the first part of our development:

Project Definition & Scope: We refined our problem statement and objectives, deciding to focus on a single-camera system that dynamically tracks drones instead of using multiple fixed cameras. This change improves system efficiency and paves the way for future integration of directional jamming techniques.

Background Research: We explored existing drone detection methods, including machine learning-based computer vision, RF signal analysis, and acoustic sensors. This research helped us identify opportunities for innovation, particularly in the tracking mechanism.

13. ACHIEVED RESULTS

Requirements Gathering & Analysis: We established the functional and non-functional requirements, ensuring the system can detect and track drones in real-time, provide a live monitoring interface, and potentially integrate additional detection methods.

System Design & Architecture: The architecture has been adapted to include a camera mounted on a dual-rotor system, allowing full sky coverage and precise tracking. We also defined the integration between the machine learning model, camera movement system, and web interface.

13. ACHIEVED RESULTS

Prototyping: We have been training the machine learning model, leaving it running for extended periods to improve accuracy. We are now confident that out model is robust and able to function in real world scenarios.

Project Management & Communication: We have maintained strong communication within the team, assigning clear responsibilities. Blog posts have been published to document progress, and we are actively engaging with potential partners and stakeholders.

With these foundations in place, the next phase will focus on assembling the prototype, integrating hardware and software, and refining our tracking and detection system.

13. ACHIEVED RESULTS: MACHINE LEARNING ALGORITHM TRAINING

1. train/box_loss – Bounding Box Loss

Measures the error in predicting the position and size of bounding boxes.

Result: Decreases consistently, showing that the model is learning to localize objects better.

2. train/cls_loss – Classification Loss

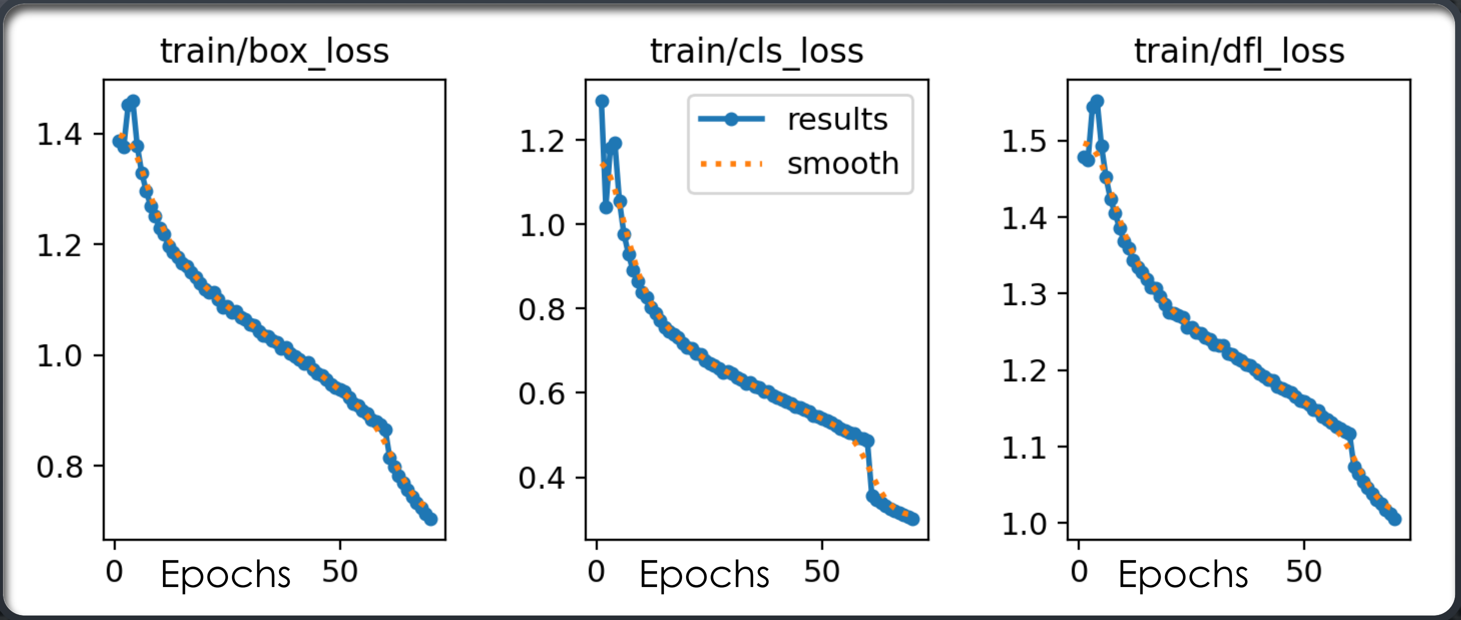
Measures how well the model classifies detected objects.

Result: Drops gradually, indicating improvement in object classification.

3. train/dfl_loss – Distribution Focal Loss

Related to the smoothness of bounding box localization.

Result: Steady decrease, suggesting stable training.



Conclusion:

Training losses are decreasing smoothly, indicating that the model is learning properly without signs of instability or divergence.

13. ACHIEVED RESULTS: MACHINE LEARNING ALGORITHM TRAINING

1. val/box_loss – Bounding Box Loss on Validation

Measures bounding box error on the validation set.

Result: Drops quickly and stabilizes, showing no overfitting.

2. val/cls_loss – Classification Loss on Validation

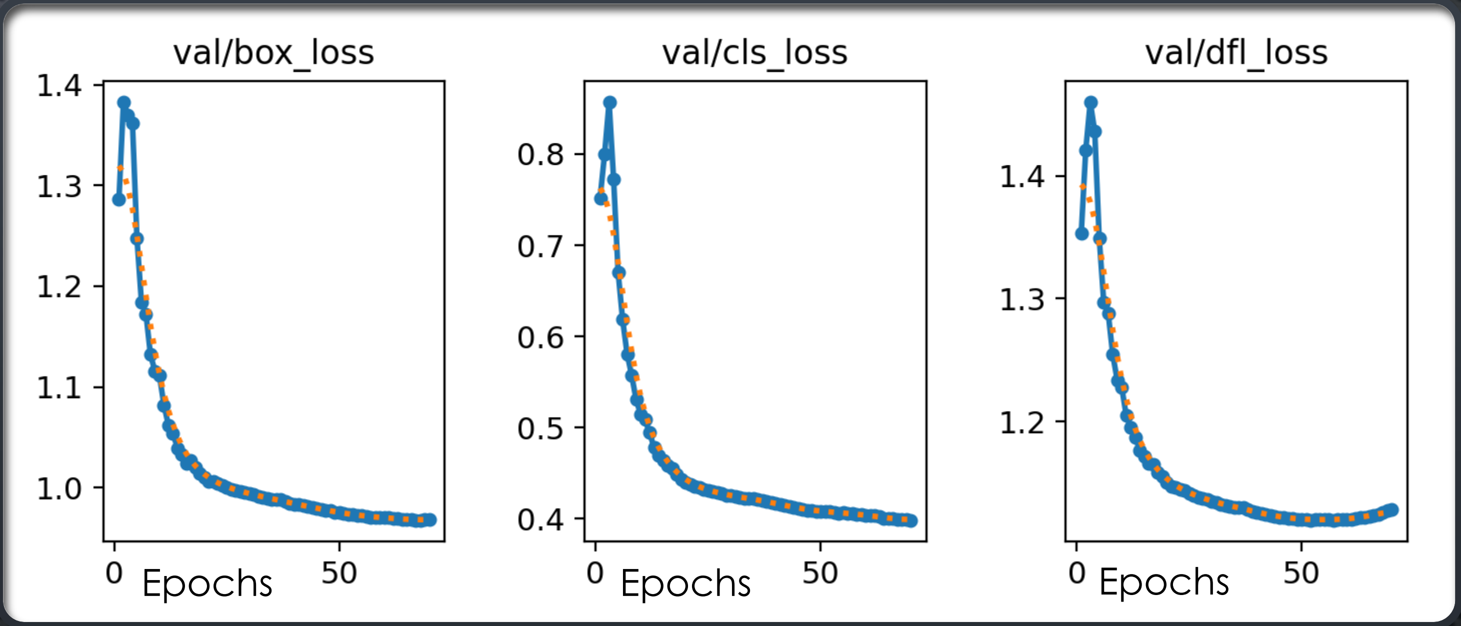
Measures classification accuracy on unseen data.

Result: Decreases and levels out, indicating good generalization.

3. val/dfl_loss – Distribution Focal Loss on Validation

Related to localization smoothness on the validation set.

Result: Follows training trend, suggesting balanced learning.



Conclusion:

Validation losses decrease consistently and stabilize without increasing, meaning the model generalizes well and avoids overfitting.

13. ACHIEVED RESULTS: MACHINE LEARNING ALGORITHM TRAINING

1. metrics/precision(B) – Precision

Measures the proportion of correct detections out of all detections made.

Result: Reaches high values (>0.95), meaning few false positives.

2. metrics/recall(B) – Recall

Measures how well the model finds all relevant objects in the image.

Result: Increases and stabilizes above 0.96 — a very strong result.

3. metrics/mAP50(B) – Mean Average Precision at IoU ≥ 50%

Measures detection accuracy when there is at least 50% overlap between predicted and ground truth boxes.

Result: Reaches values close to 0.98, showing excellent object detection performance.

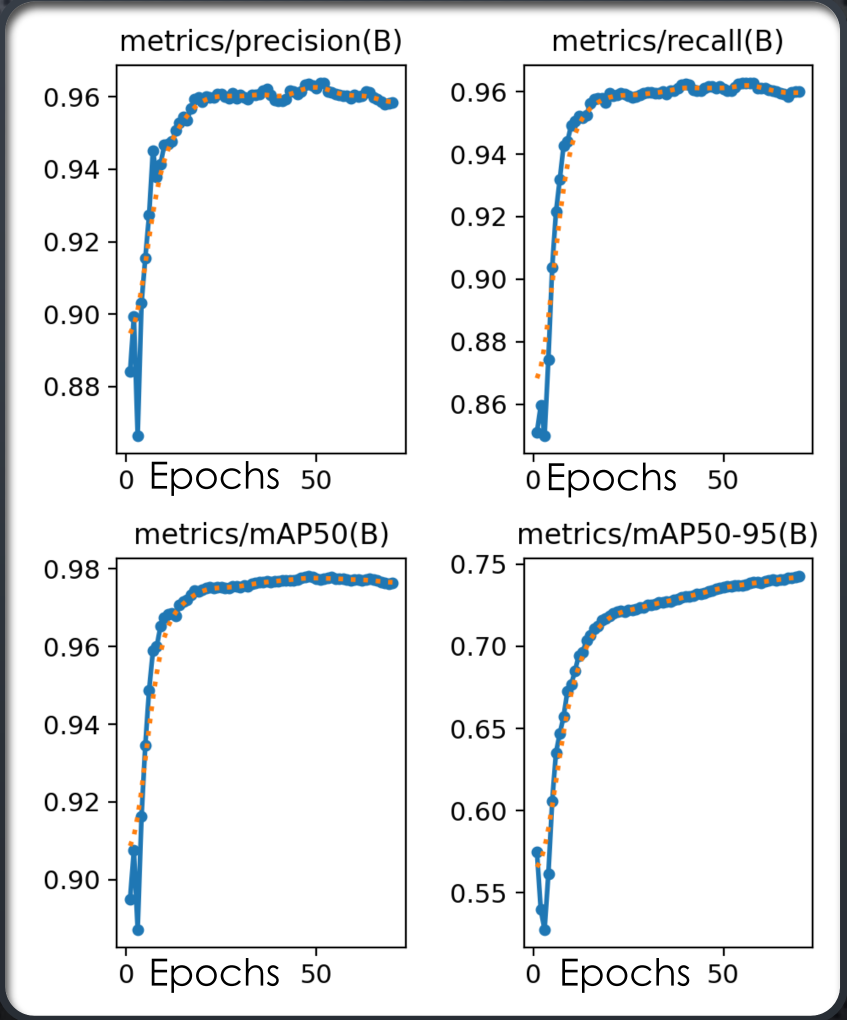
4. metrics/mAP50-95(B) – Mean Average Precision at IoU 50% to 95%

A stricter metric that evaluates accuracy across multiple IoU thresholds.

Result: Stabilizes around 0.75, indicating solid performance across various object sizes and locations.

Conclusion:

The model shows high precision, recall, and mAP, meaning it can detect and classify objects accurately, with very few mistakes.



14. CHALLENGES FACED BY THE TEAM

The main challenges the team faced in the first part of the project were:

Understanding how to detect the drone – Identifying the most effective detection methods and exploring different approaches to ensure reliable differentiation between drones and other flying objects.

Difficulties in training the Machine Learning Algorithm (MLA) – The high computational cost of training the model posed a significant challenge, requiring careful optimization and resource management.

15. Deviations from Original Schedule

The main causes for deviations from the original schedule were:

1. **Underestimation of task complexity** – Understanding how to detect the drone required exploring multiple approaches, which took longer than initially expected.
2. **Technical roadblocks and unforeseen issues** – Training the Machine Learning Algorithm (MLA) was challenging due to its high computational cost, delaying progress.
3. **Delays in component acquisition**

16. CONTRIBUTION OF EACH TEAM MEMBER (I)

Guilherme Martins	Francisco Rodrigues	João Firmino
Management and coordination	**Rotor integration**	**MLA Training and validation**
Engagement with Partners	Research and initial Study	Website Development
Blog Update	Interviews	Research and initial Study
Interview		

16. CONTRIBUTION OF EACH TEAM MEMBER (II)

Afonso de Mello	Guilherme Luis	Rodrigo Sanguino
Web-App Development	**Camera Rotation Code Development**	**Camera Rotation Code Development**
Engagement with Partners	Research and initial Study	Research and initial Study

17. CORRECTED SCHEDULE