Drone mission planning and control

Contributors: J. Capitan (University of Seville, Spain), R. Cunha (IST, Portugal)
Presenter: Prof. Ioannis Pitas
Aristotle University of Thessaloniki
pitas@aiia.csd.auth.gr

www.multidrone.eu

Presentation version 1.3

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Drone mission planning and control

- **Audiovisual shooting mission definition.**
- Multiple drone mission planning.
- Multiple drone mission control:
  - Single drone flight control.
  - Gimbal control.
  - BMMCC control.
  - Multiple drone control architecture.
  - Drone formation control.
  - Collision avoidance.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Mission Planning Vocabulary

- MULTIDRONE **Shooting Mission**: list of **actions.**
- Types of actions:
  - **Shooting Actions**: drone + camera
    e.g., Lateral Tracking, Fly-Over, Orbit, …
  - **Navigation Actions**: drone action only, does not involve shooting
    e.g., Take-off, Land, Go-to-waypoint, …
- Shooting Actions are *event-triggered:*
  - A start event is associated to each Shooting Action, which will trigger the action when it occurs.
    E.g., target reaches a milestone, start of race, …

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Problem definition

- Given N drones with known positions.
- Given M single-drone tasks with initial position, initial time (event) and time duration.
- Solve a Multi-Robot Task Allocation problem to maximize time that drones are covering shooting tasks.
- Tasks correspond to Director Shooting Actions (SAs). SAs with several drones are split into several single-drone tasks.

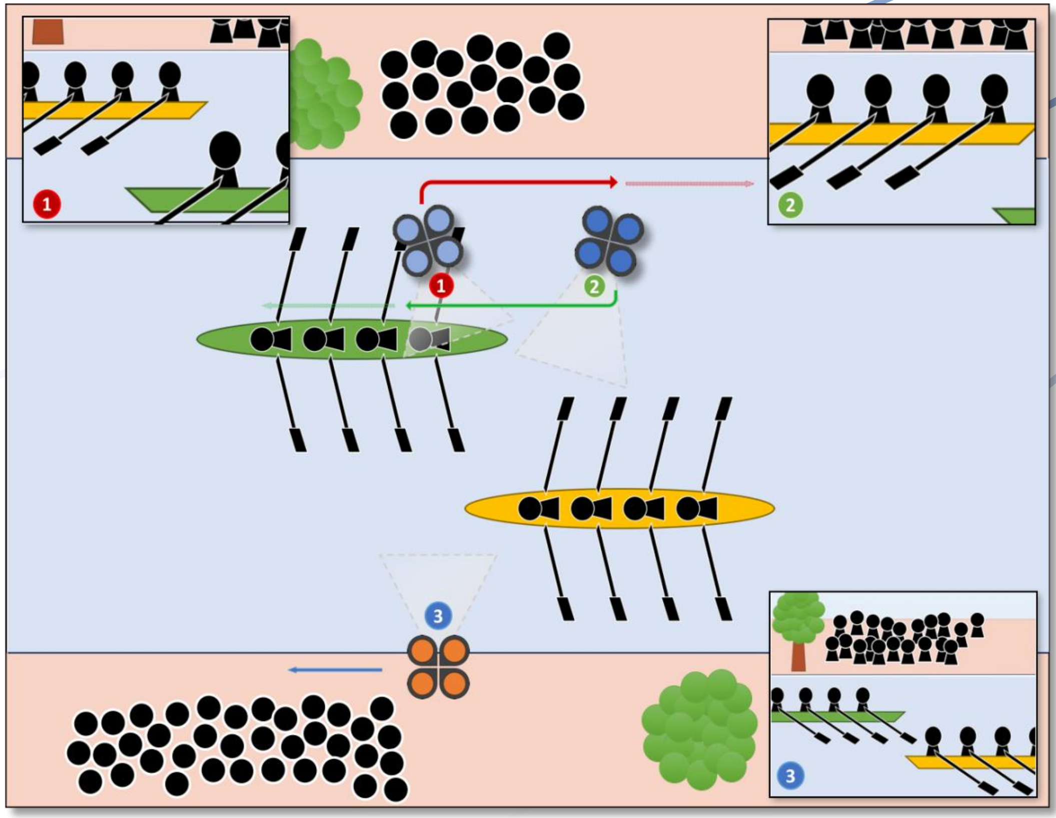
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Shooting Action Parameters

- **Shot type:**
  - Lateral shot, Orbital shot, etc.
- **Zoom type:**
  - Long shot, Medium shot, Close-up, etc.
- **Start position** for the drone and the camera look-at position.
- **Triggering event.**
- Duration.
- Target ID.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Example mission: Boat race scenario



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

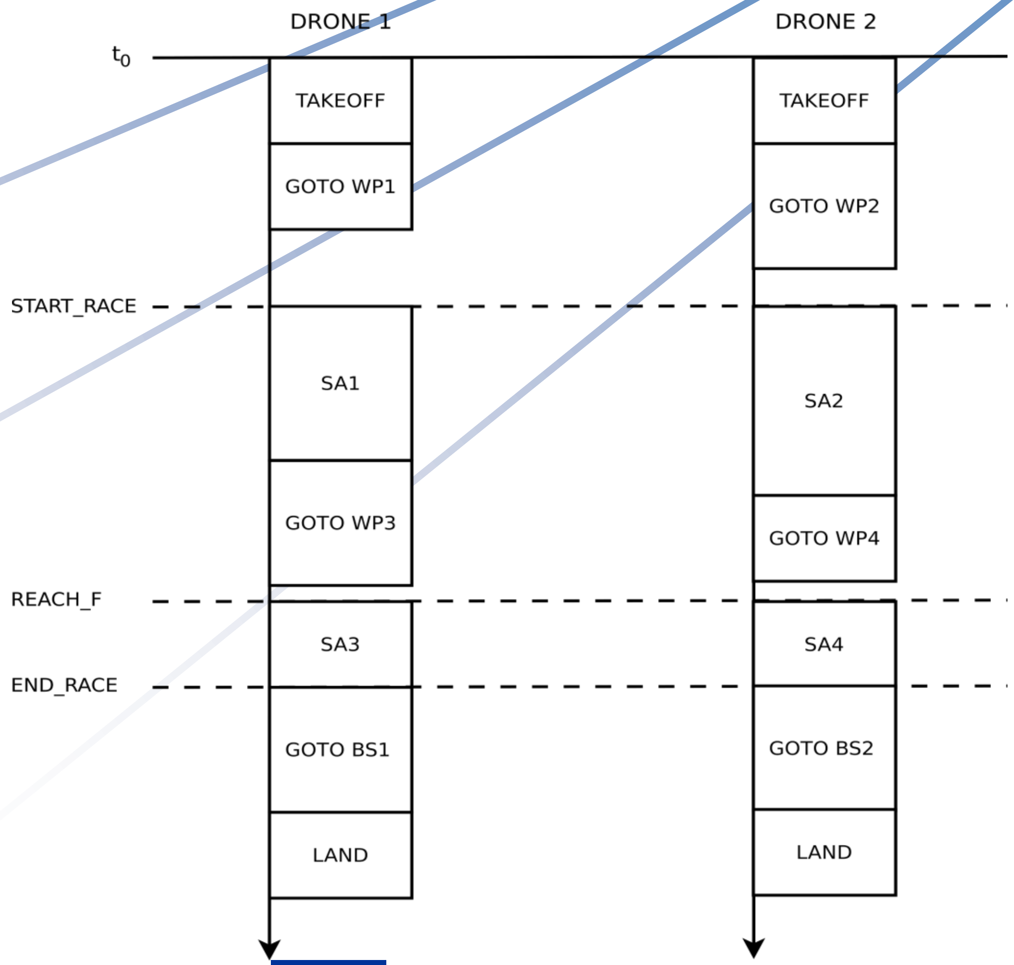
Example mission:
Boat race scenario

From start of race until approaching finish line:

- Drone 1 takes a lateral shot (SA1);
- Drone 2 takes a frontal shot (SA2).

At finish line:

- Drone 1 holds position for photo finish (SA3);
- Drone 2 takes an over-the shoulder shot (SA4).



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Drone mission planning and control

- Audiovisual shooting mission definition.
- **Multiple drone mission planning.**
- Multiple drone mission control:
  - Single drone flight control.
  - Gimbal control.
  - BMMCC control.
  - Multiple drone control architecture.
  - Drone formation control.
  - Collision avoidance.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Assumptions

- Deterministic model. Target trajectory can be predicted exactly, times for event occurrence too.
- Drones' positions after executing a task can be predicted.
- In reality there will be uncertainties, include threshold in time event to reach start position before.
- Flying time (battery) bounded. Main objective is not reducing battery consumption but filming as much as possible.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

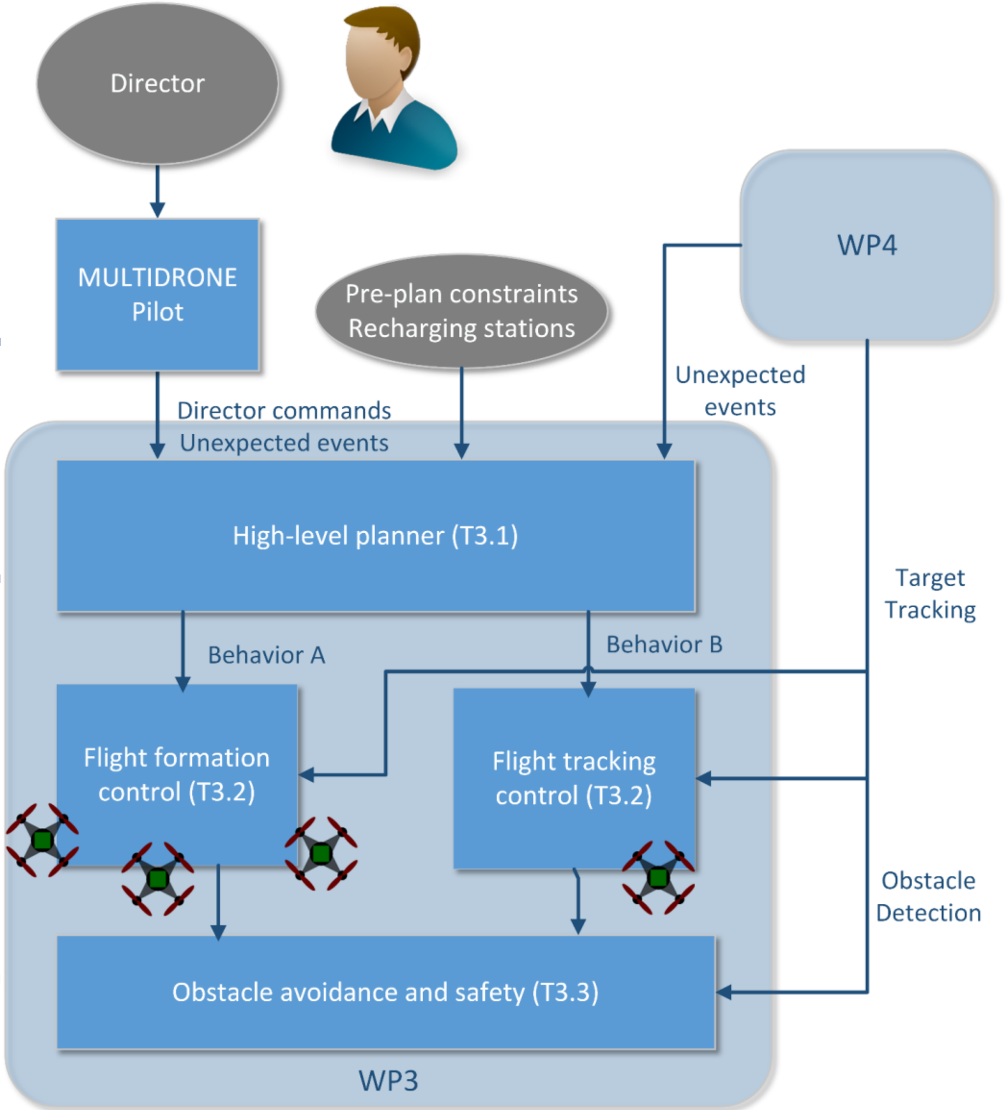
Solution

MultiDrone

- Discretize time intervals of each task into subintervals, building a time graph.
- Each graph node encodes position, time and remaining battery.
- Objective: maximize the amount of subintervals that each drone cover (film).
- Modification of Dijkstra’s algorithm solves optimally the time graph for one drone.
- Multi-drone solution computed with greedy strategy: applying the one-drone algorithm iteratively, and removing visited edges in graph.
- In case of several graph solutions covering same number of tasks, choose that with less navigation actions.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

High-level pre-production/production mission planning



- **High-level planner** assigns different behaviours/tasks to the multidrone team according to director and environmental requirements.
- The multidrone planner needs to be **scalable** with multiple actors, since on-line re-planning could be needed as events happen or execution is performed.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

High-level planner

- Shooting Mission translated to list of Shooting Actions with triggering events.

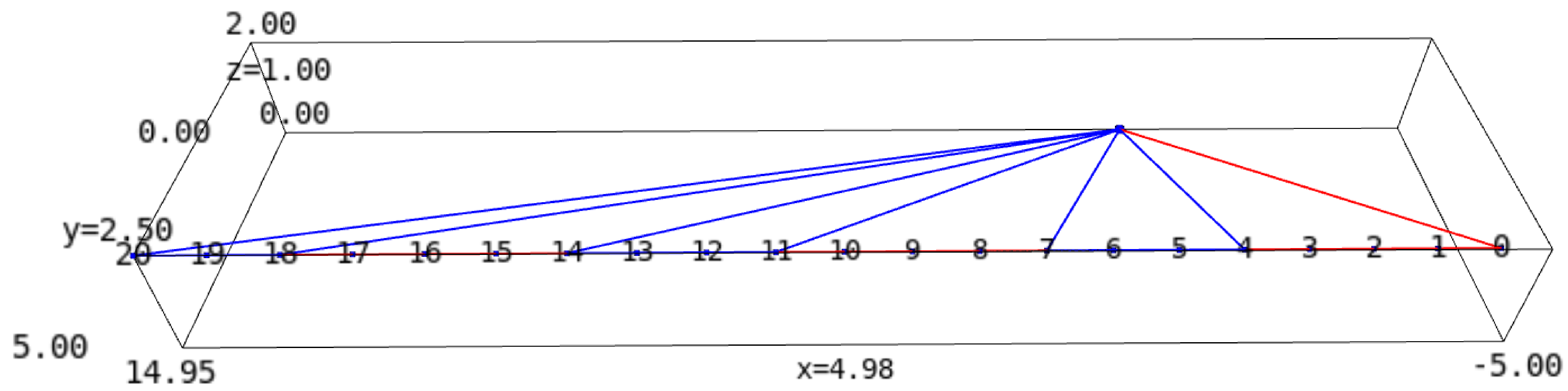
- Tasks correspond to SAs, multi-drone SAs split into several single-drone tasks.
- Each task has a start location, start time and duration.

- Computes the plan: allocates tasks to drones fulfilling time and precedence constraints (Multi-Robot Task Allocation problem).
- MRTA problem definition:
  - N drones with known positions.
  - M single-drone tasks, each one with its time window.
  - Objective: maximize time where drones are covering (filming) tasks.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Example 1

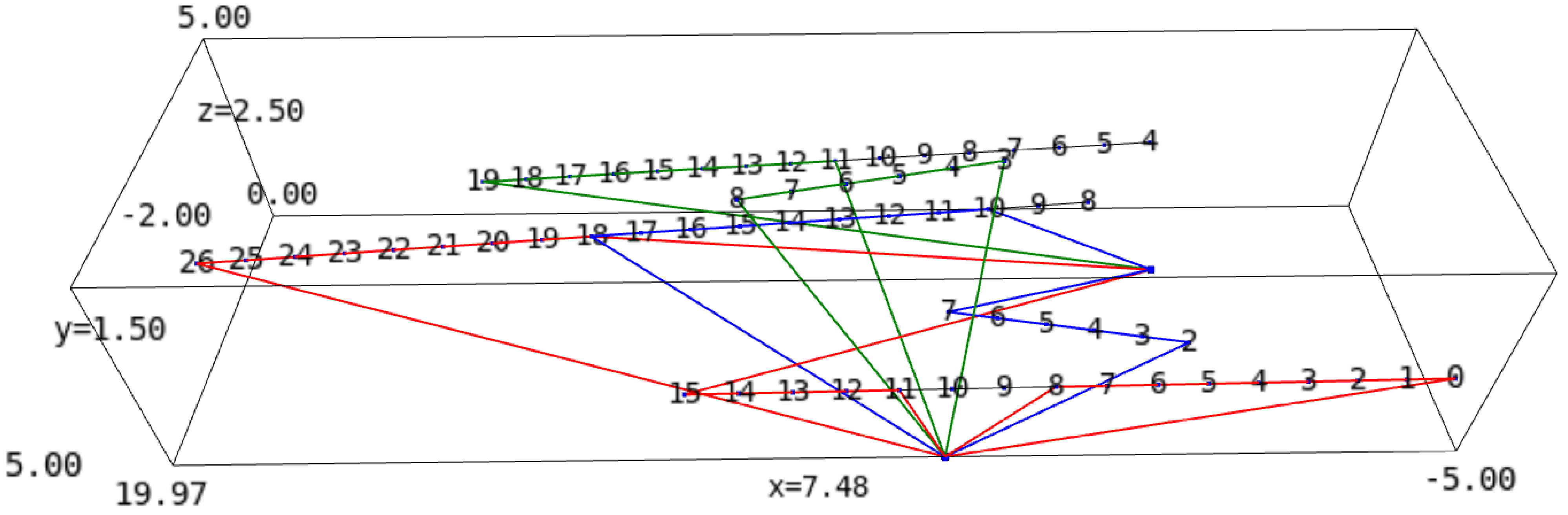
- This example shows how two drones cover a long task in turns, due to the battery constraint.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Example 2

- 3 drones covering 5 tasks.
- Red and blue drones share one task (red one replaced at time 18 by blue).
- Some tasks could not be filmed entirely.



Path Planner

- This submodule is used by:
  - High-level Planner to estimate drone paths and flying times.
  - Onboard Scheduler to compute a path to a landing position in case of emergency.

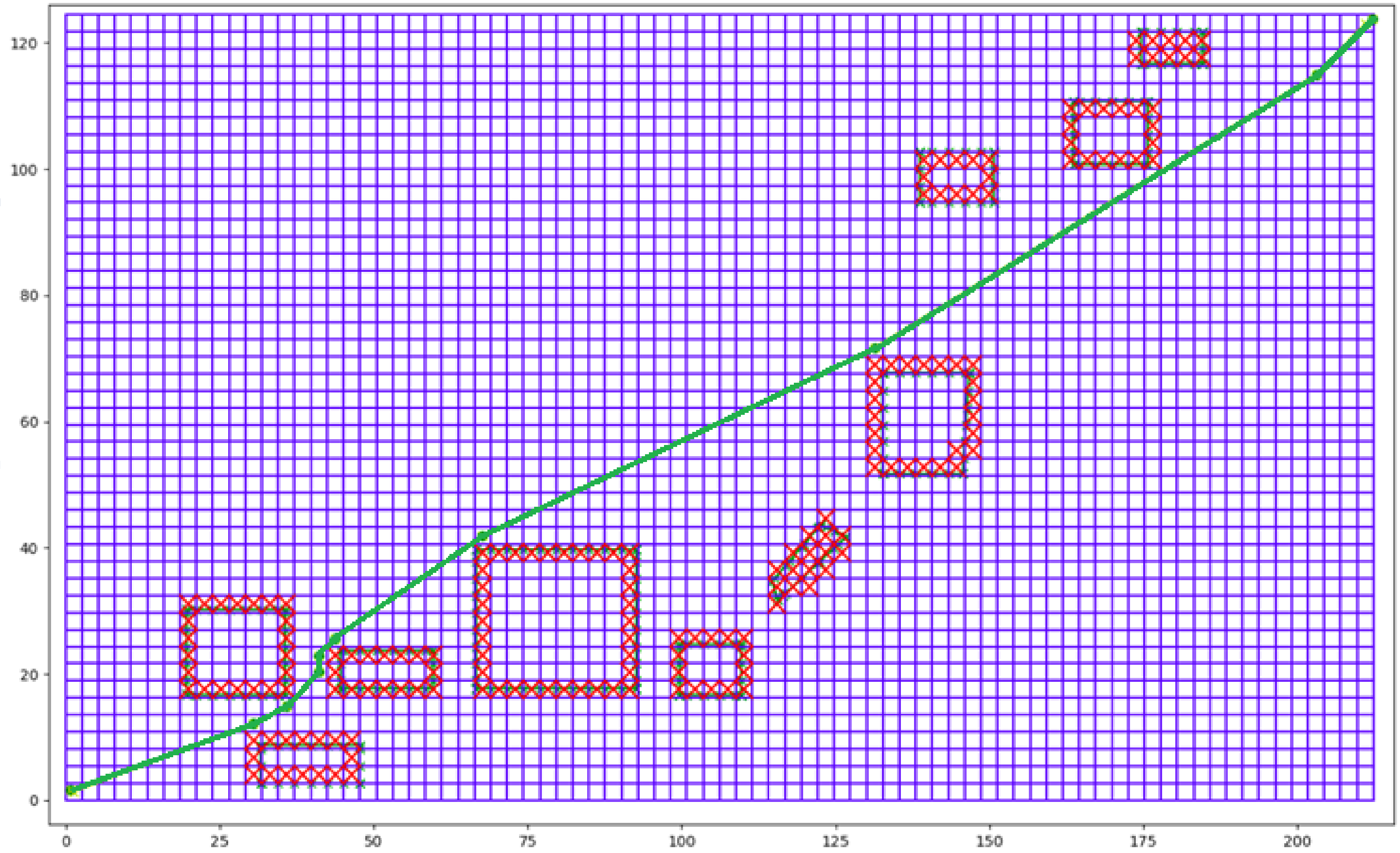
- Navigation map implemented as a grid. Obtained from Semantic Map.
  - Semantic annotations are indicated as KML features.
  - Geodesic coordinates translated into Cartesian.
  - No-fly poligons become occupied cells in grid.

- Safe path computed using A* search algorithm. Fast for simple solution spaces.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Example

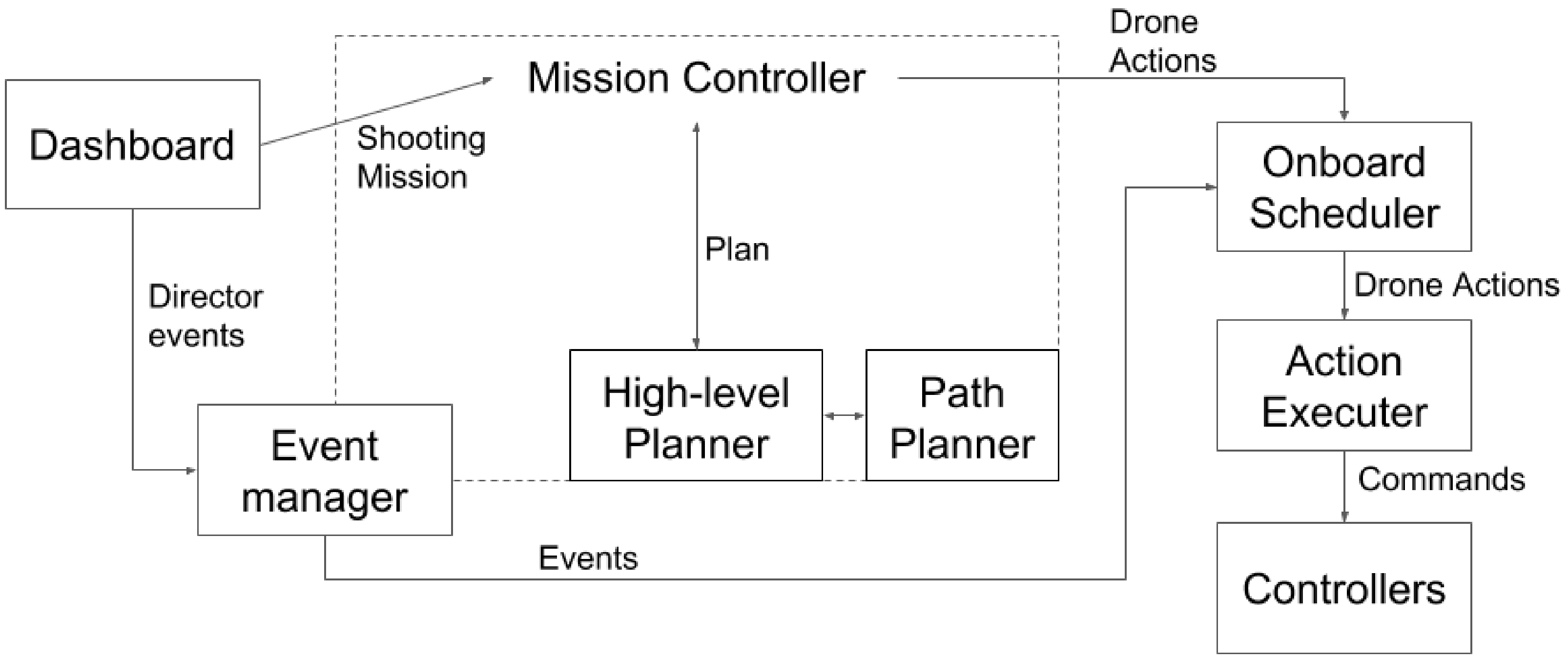
- Path from one corner to the other. Buildings labeled as no-fly zones (obstacles represented as red crosses in the grid).
- Solved in 66 ms.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Mission Planning architecture

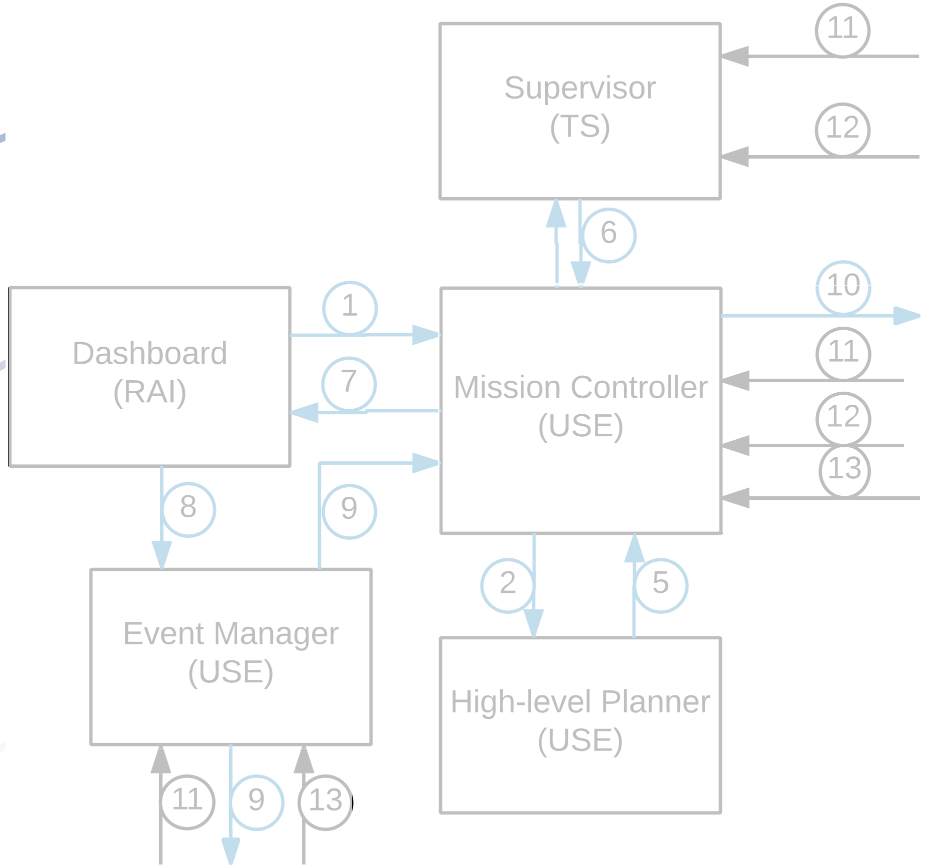
MULTIDRONE Planning



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Mission Planning/Control
On ground modules

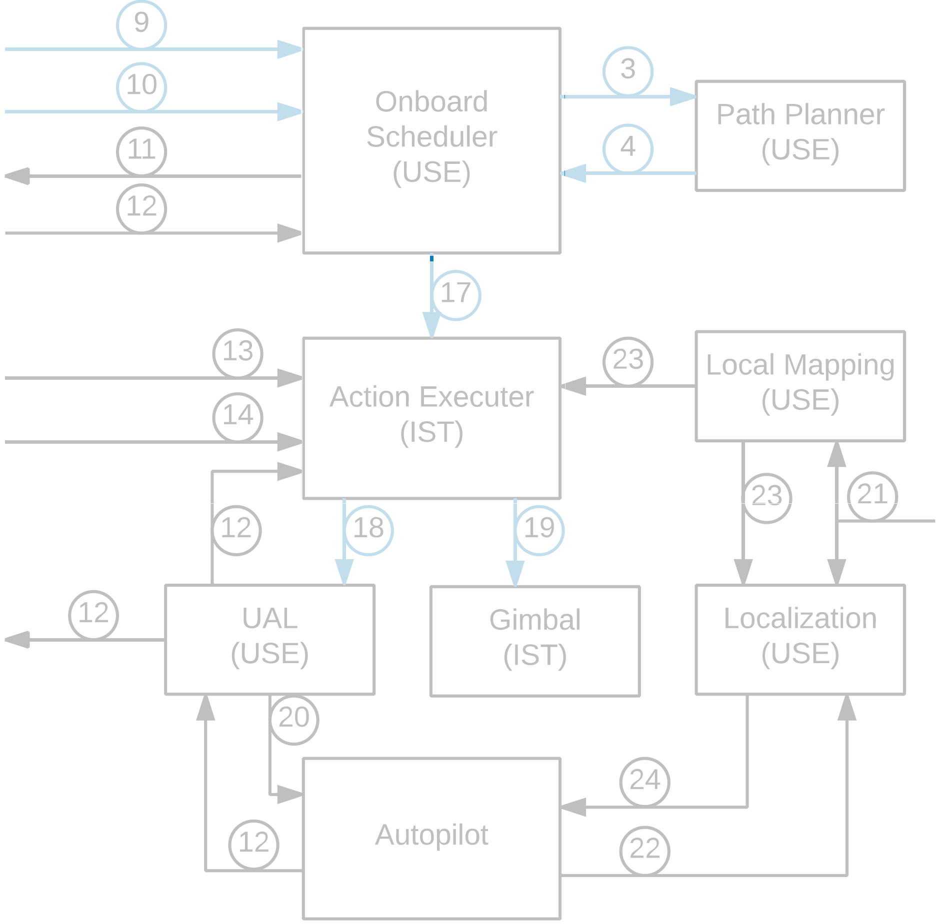
- **Mission Controller:**
  - Interacts with **High-level Planner** to produce a mission plan.
  - Monitors mission execution.
  - Asks for replanning if needed.
- **Event Manager:**
  - Receives, manages and generates events.
  - Sends events to drones to start and stop action execution.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Mission Execution
On drone modules

- **Onboard Scheduler:**
  - Receives list of actions.
  - Receives events to trigger action execution.
  - Activates the Action Executer.
  - Sends drone status to ground.
- **Action Executer:**
  - Translates Shooting Actions into desired drone+camera configurations.
  - Interacts with other modules to produce commands for autopilot, camera and gimbal.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Drone mission planning and control

- Audiovisual shooting mission definition
- Multiple drone mission planning.
- **Multiple drone mission control:**
  - **Single drone flight control.**
  - Gimbal control.
  - BMMCC control.
  - Multiple drone control architecture.
  - Drone formation control.
  - Collision avoidance.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Drone operation/control modes

MultiDrone

- **Manual operation:**
  - 1 pilot and 1 cameraman per drone.
  - Scalability and operation cost issues, when multiple drones operate.
- **Automatic operation:**
  - 1 drone or multiple drones.
  - Formation control.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

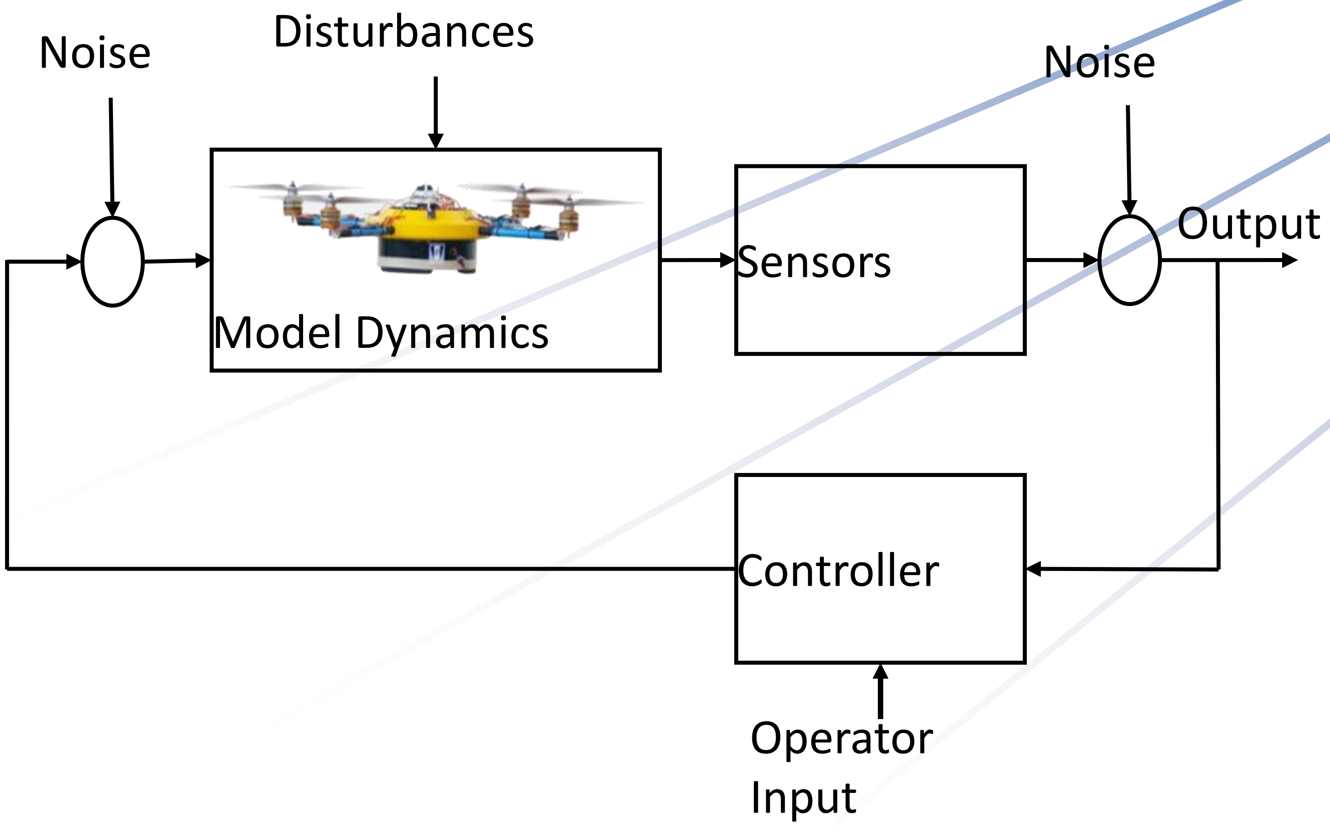
Manual operation/control

- **Manual operation**
    - 1 pilot and 1 cameraman per drone.
    - 2 Radio (TX/RX) links per drone.
- Pilot radio controls:
    - On screen telemetry.
    - POV camera.
    - Sticks control drone pitch, roll and yaw.
- Cameraman radio controls:
    - Control gimbal and camera parameters.
    - Views AV shooting camera.
- Scalability concerns.

Pilot control
(FUTABA 14SG)
- 2.4GHz air receiver.
- Programmable interface.
- More than enough range for VLOS mode (<500m in Greece).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Automatic drone operation: Drone as Control System



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Control Objectives – Trajectory Tracking

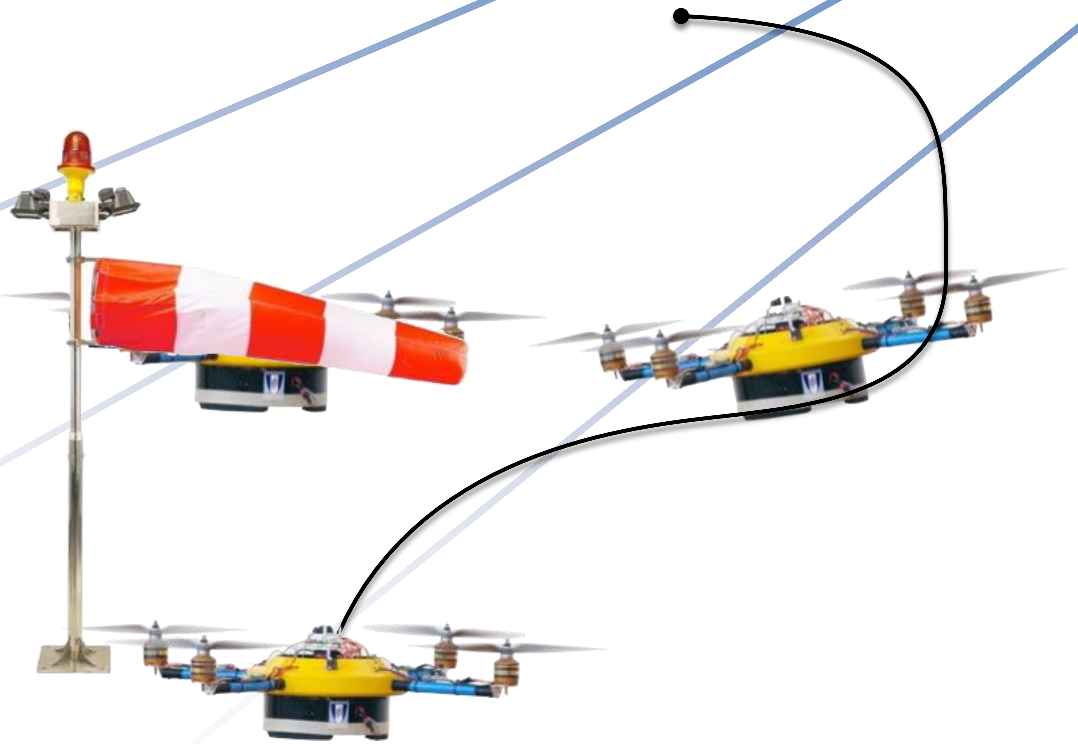
Track a trajectory.

Realistic model.

Robustness to disturbances.

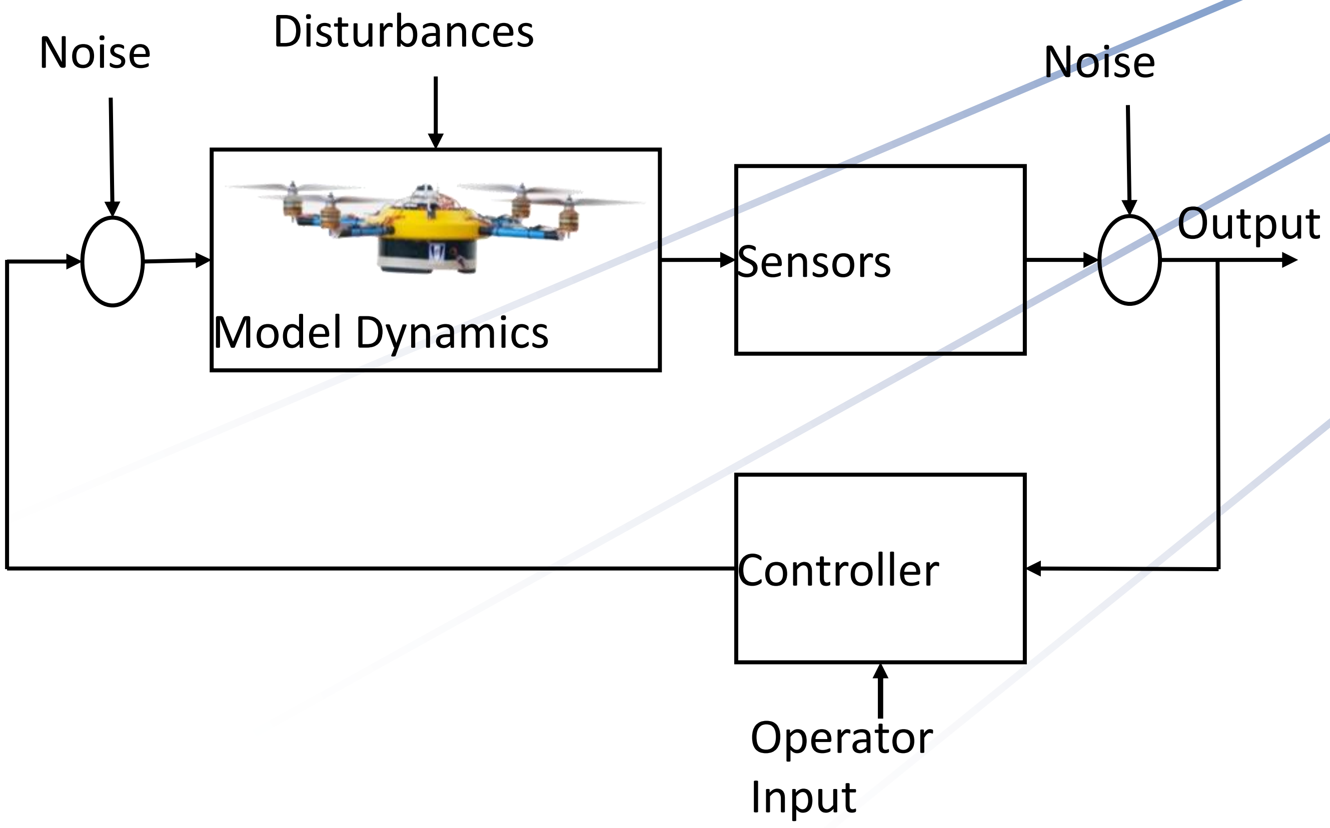
Bounded actuation.

Large basin of attraction.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Drone as Control System



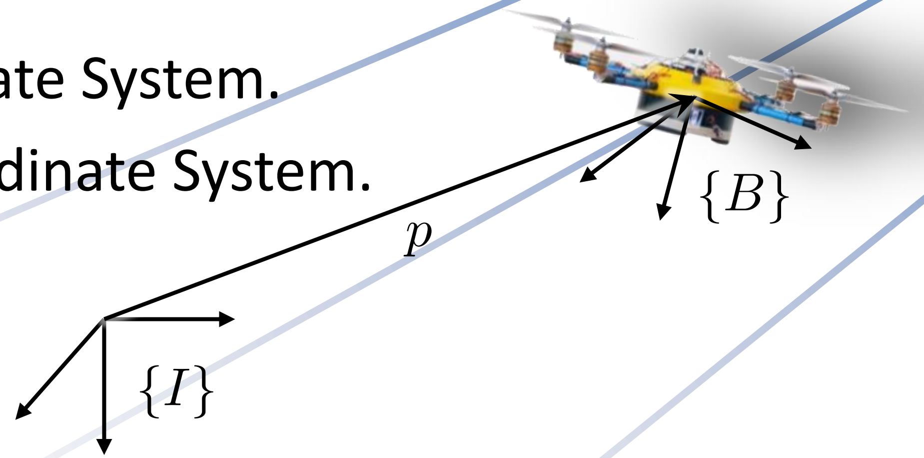
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Rigid-body equations of motion (I)

Reference Frames:

$\{I\}$Inertial Reference Coordinate System.

$\{B\}$Body-fixed Reference Coordinate System.



$p \in \mathbb{R}^3$ – Position of $\{B\}$ relative to $\{I\}$

$R \in \mathbb{SO}(3)$ – Rotation from $\{B\}$ to $\{I\}$

$v \in \mathbb{R}^3$ – Linear velocity of $\{B\}$ relative to $\{I\}$

$\omega \in \mathbb{R}^3$ – Angular velocity of $\{B\}$ relative to $\{I\}$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

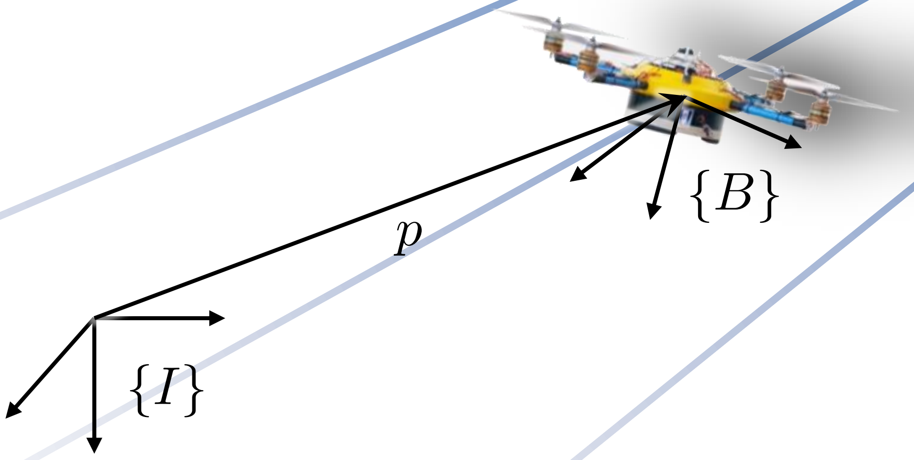
Rigid-body equations of motion (II)

Kinematics:

$$\begin{cases} \dot{p} = v \\ \dot{R} = RS(\omega) \end{cases}$$

Dynamics:

$$\begin{cases} m\dot{v} = f \\ J\dot{\omega} = -S(\omega)J\omega + n \end{cases}$$



$$S(\omega)a = \omega \times a, \text{ for } \omega, a \in \mathbb{R}^3$$

$m \in \mathbb{R}$ – mass

$J \in \mathbb{R}^{3\times 3}$ – Tensor of inertia expressed in $\{B\}$

$f \in \mathbb{R}^3$ – External forces expressed in $\{I\}$

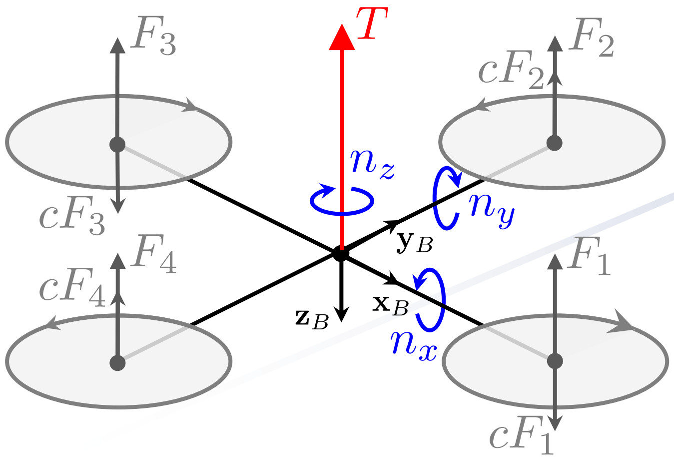
$n \in \mathbb{R}^3$ – External moments expressed in $\{B\}$

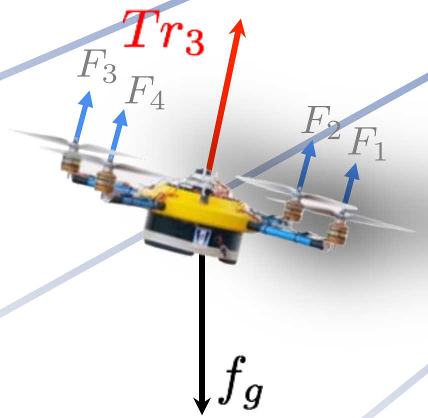
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Quadrotor dynamic modeling

MultiDrone

Two pairs of counter-rotating rotors:





$$\begin{bmatrix} T \\ n_x \\ n_y \\ n_z \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & b & 0 & -b \\ -b & 0 & b & 0 \\ c & -c & c & -c \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix}$$

$$r_3 = Re_3 = R \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$f_g = mge_3$$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

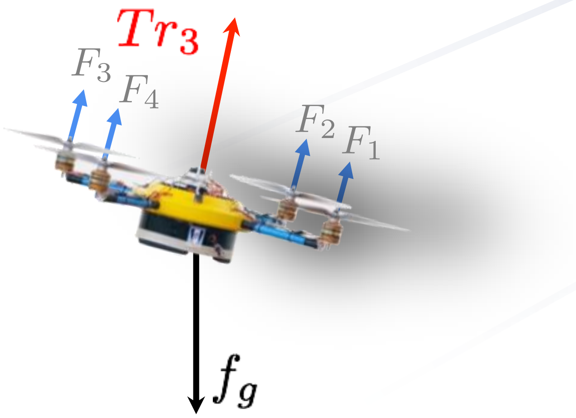
Quadrotor dynamic modeling

Dynamics:

$$\begin{cases} m\dot{v} = f \\ J\dot{\omega} = -S(\omega)J\omega + n \end{cases}$$

$$f = -Tr_3 + f_g + d$$

$n \in \mathbb{R}^3$ – Torque commands



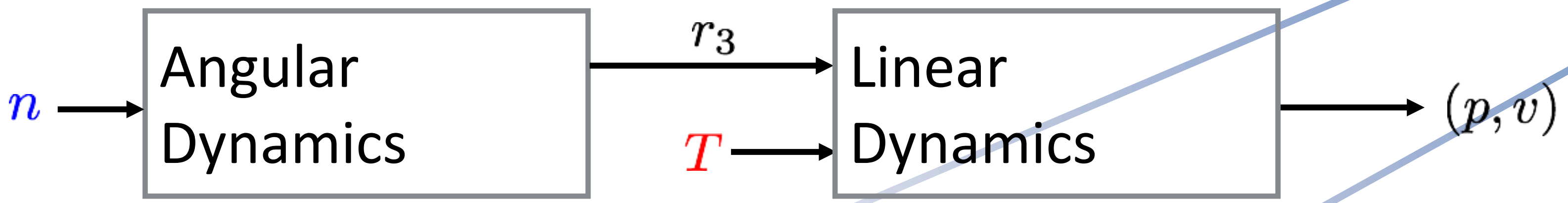
$Tr_3 \in \mathbb{R}^3$ – Thrust force

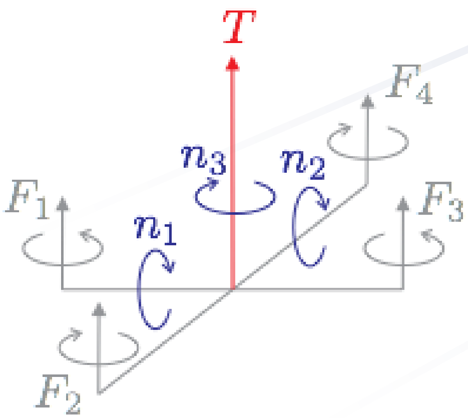
$f_g \in \mathbb{R}^3$ – Gravitational force

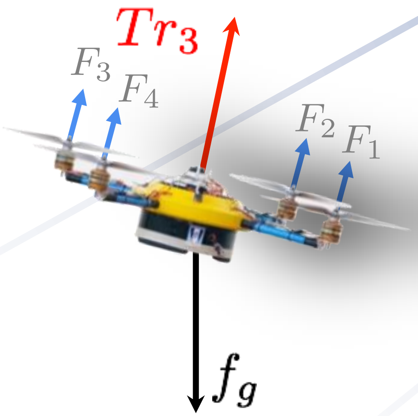
$d \in \mathbb{R}^3$ – Disturbance forces

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Quadrotor dynamic modeling







State (p, v, R, ω)

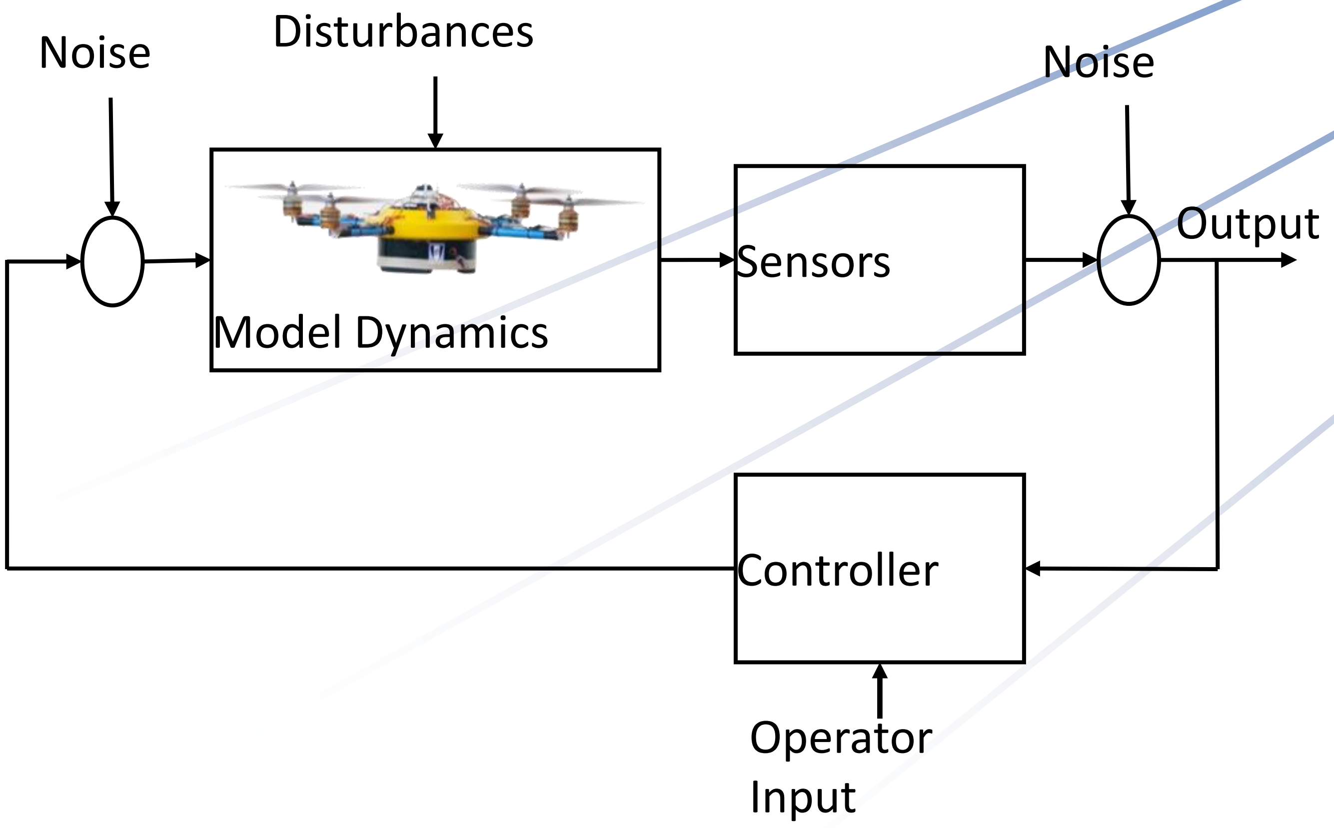
Input (T, n)

Underactuated system: 12 states, 4 inputs

Flat output $(p,\ \psi) \in \mathbb{R}^4$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Drone as Control System

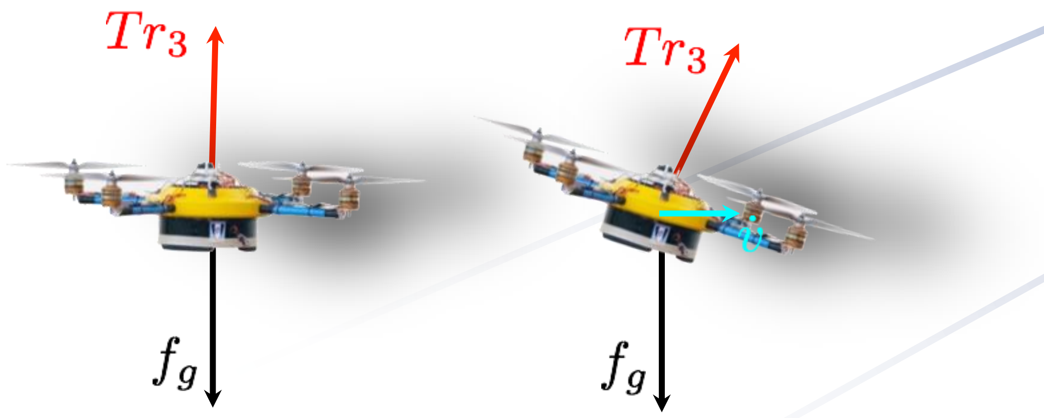


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Trajectory Tracking Control

Underactuated system: 12 states, 4 inputs

At rest / Accelerating



$\dot{v} = 0$ | $\dot{v} \neq 0$

$Tr_3 = f_g$ | $Tr_3 = f_g - m\dot{v}$

Control objective:

Steer the position to a desired trajectory

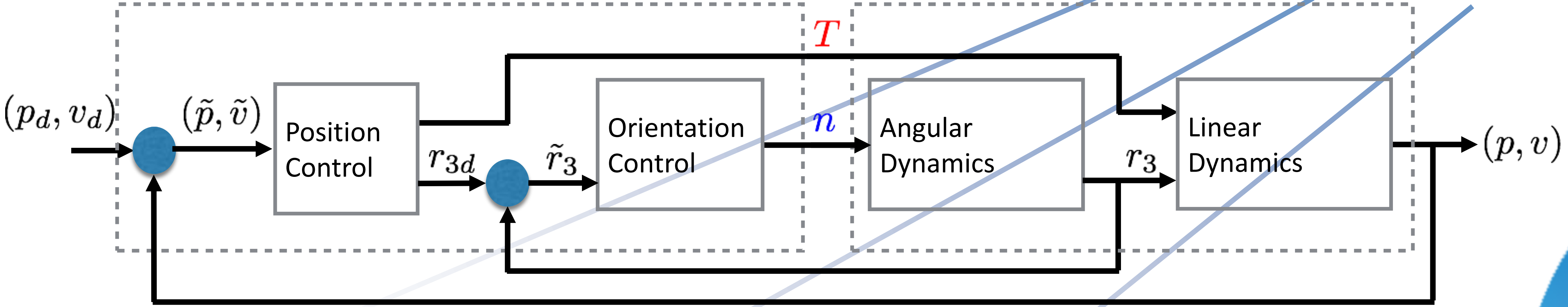
$p(t) \to p_d(t)$

using $(T\ n)$ as input.

Can only prescribe 4 states:
e.g. 3D position and rotation about z-axis.

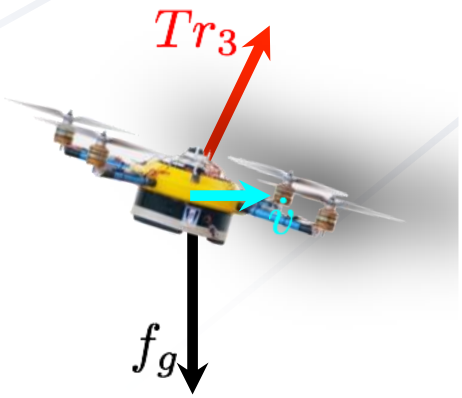
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Trajectory Tracking Control



Simplest Position Controller yields mass-spring-damper system

$$m\dot{\tilde{v}} = -k_1\tilde{p} - k_2\tilde{v}$$

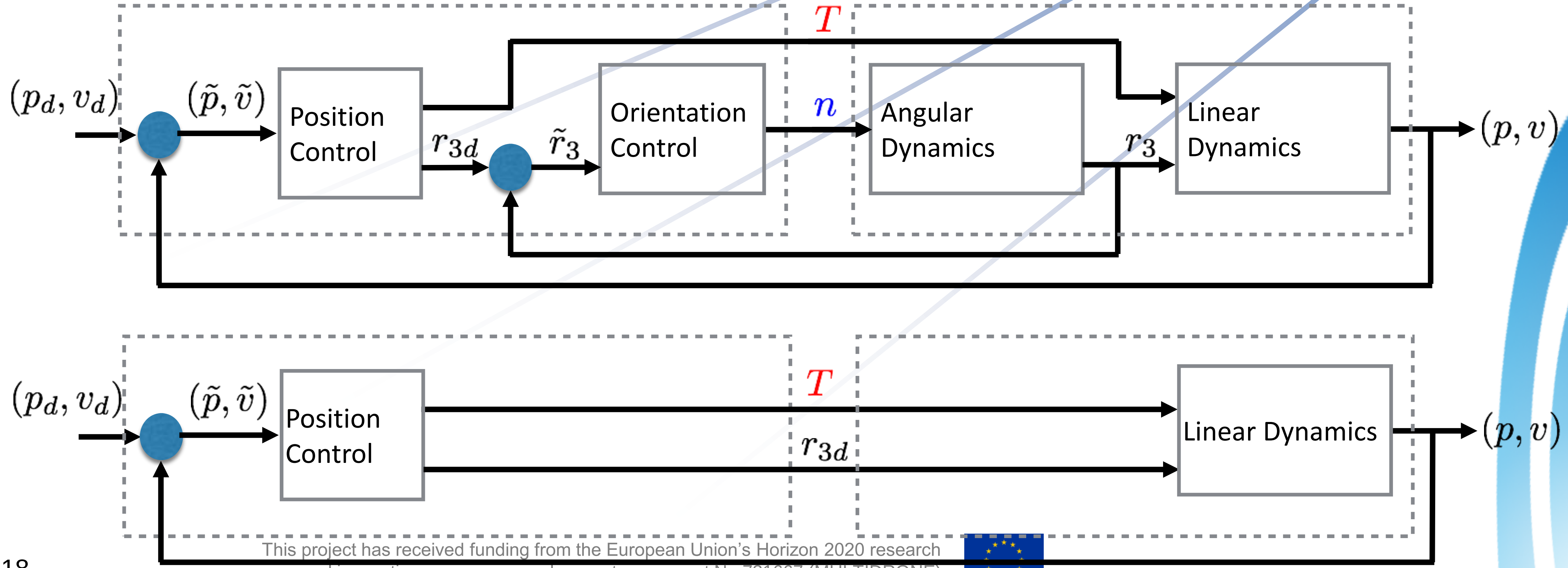


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Hierarchical Control

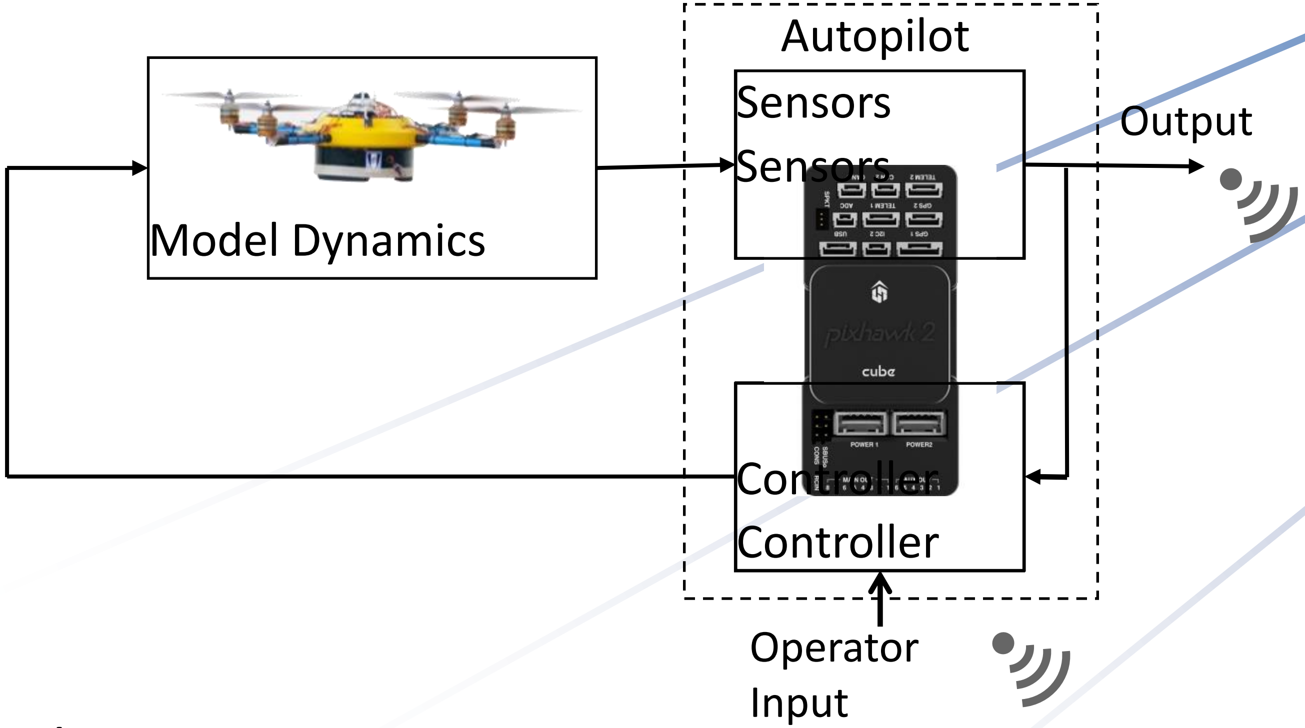
Explores time-scale separation:

- *Fast* inner-loop dynamics – Orientation.
- *Slow* outer-loop dynamics – Position.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Autopilot – PixHawk 2.1



- Autopilot:
  Sensors (IMU, GPS, Barometer,…) + Flight Controller.
- Radio Link

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Autopilot – PixHawk 2.1

- Sensors:
  For orientation: IMU (accelerometers, gyros, magnetometers).
  For position: GPS, barometer, altimeter, …

- Flight Controller:
  Modes (hierarchical control):

  1. Linear Position control
  2. Linear Velocity control
  3. Angular Position control
  4. Angular Velocity control.

Converted to motor commands

This project has received funding from the Eu… …zon 2020 research and innovation programme under grant a… …667 (MULTIDRONE)

Drone mission planning and control

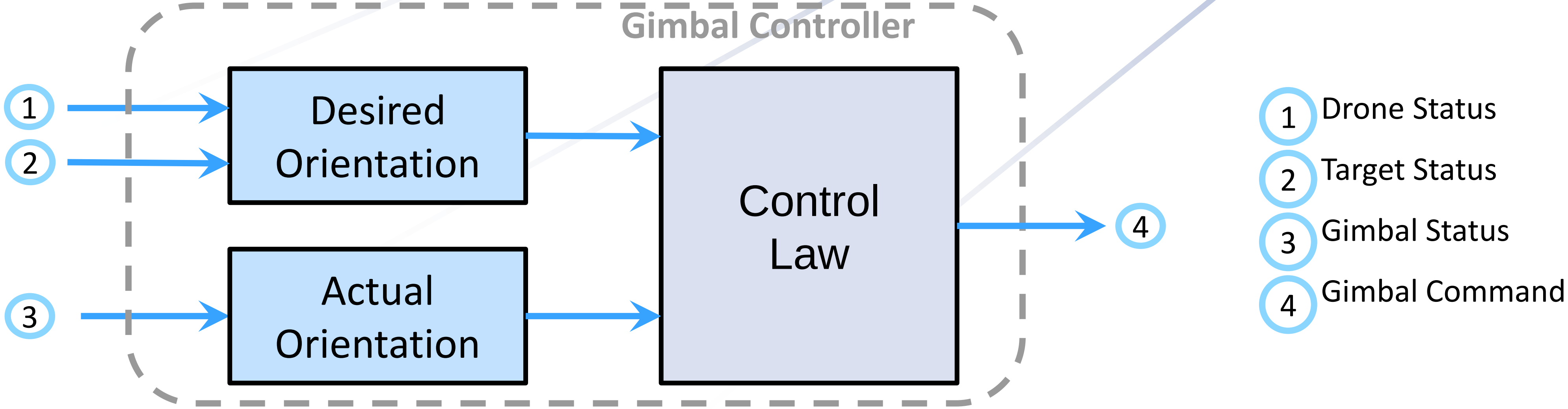
MultiDrone

- Audiovisual shooting mission definition
- Multiple drone mission planning.
- **Multiple drone mission control:**
  - Single drone flight control.
  - **Gimbal control.**
  - BMMCC control.
  - Multiple drone control architecture.
  - Drone formation control.
  - Collision avoidance.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Gimbal control

- Control objective:
  Point towards the target.
- Approach:
  Treat gimbal control independently from drone control.

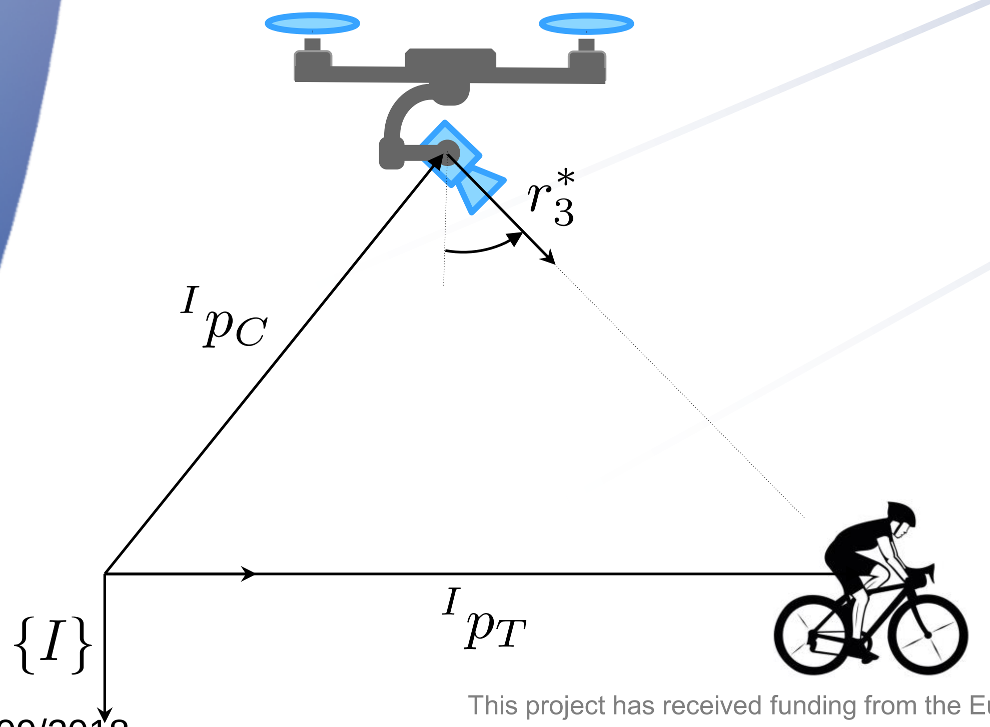


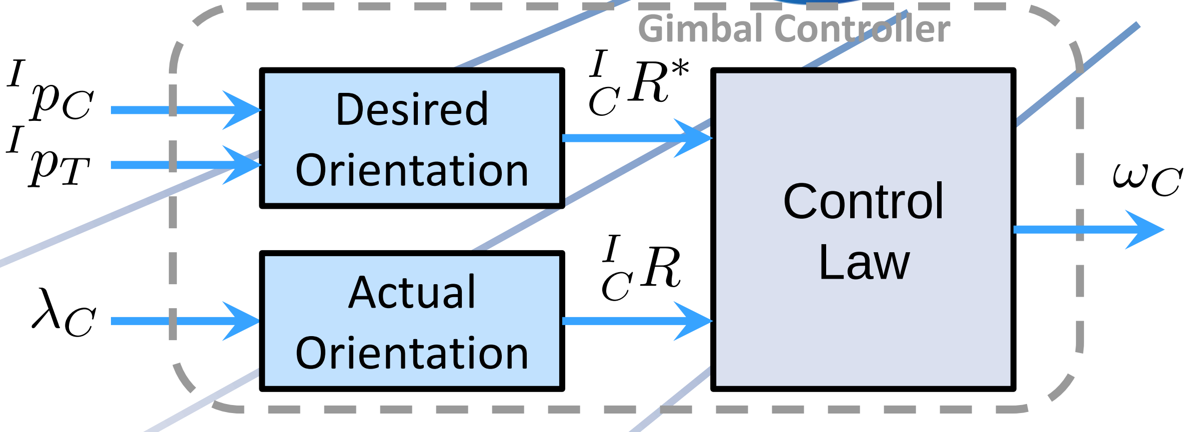
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Gimbal control

- Desired orientation

$$ {}^I_C R^* = \begin{bmatrix} r_1^* & r_2^* & r_3^* \end{bmatrix} \in \mathbb{SO}(3) $$





Desired optical axis in inertial coordinates

$$ r_3^* = \frac{{}^I p_T - {}^I p_C}{\| {}^I p_T - {}^I p_C \|} $$

Camera provides

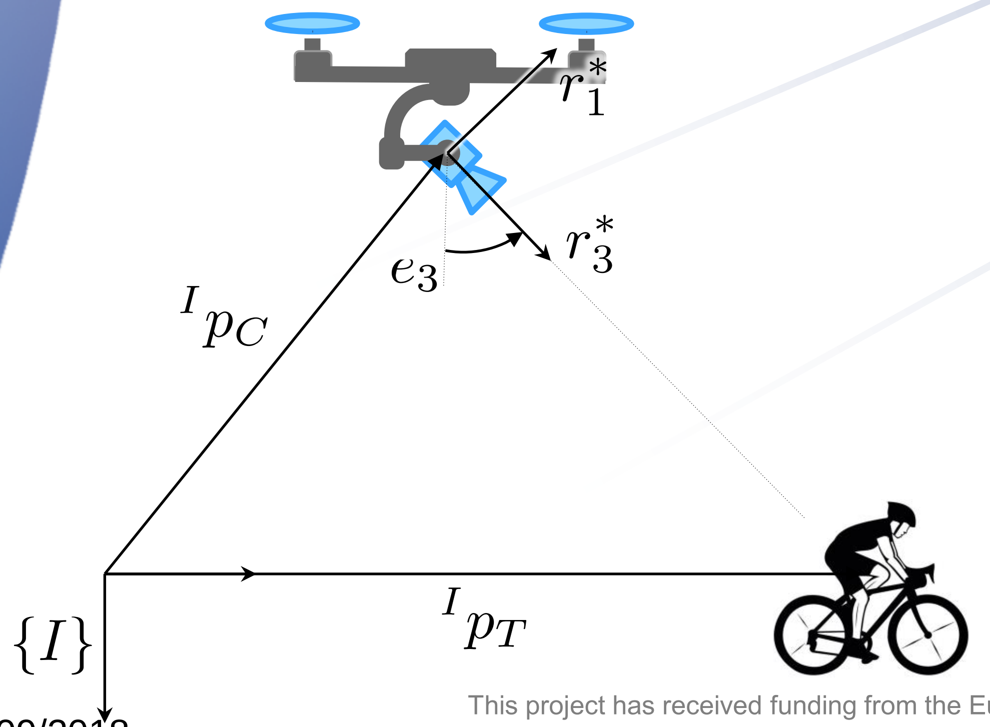
$$ {}^C_I R \frac{{}^I p_T - {}^I p_C}{\| {}^I p_T - {}^I p_C \|} $$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Gimbal control

- Desired orientation

$${}^{I}_{C}R^* = \begin{bmatrix} r_1^* & r_2^* & r_3^* \end{bmatrix} \in \mathbb{SO}(3)$$



Desired optical axis in inertial coordinates

$$r_3^* = \frac{{}^{I}p_T - {}^{I}p_C}{\|{}^{I}p_T - {}^{I}p_C\|}$$

Extra degree of freedom

1st alternative

$$r_2^* = \frac{r_3^* \times e_3}{\|r_3^* \times e_3\|}$$

$$r_1^* = r_3^* \times r_2^*$$

Keeps camera horizontally aligned

Singularity when pointing exactly downward $r_3^* = e_3$

2nd alternative

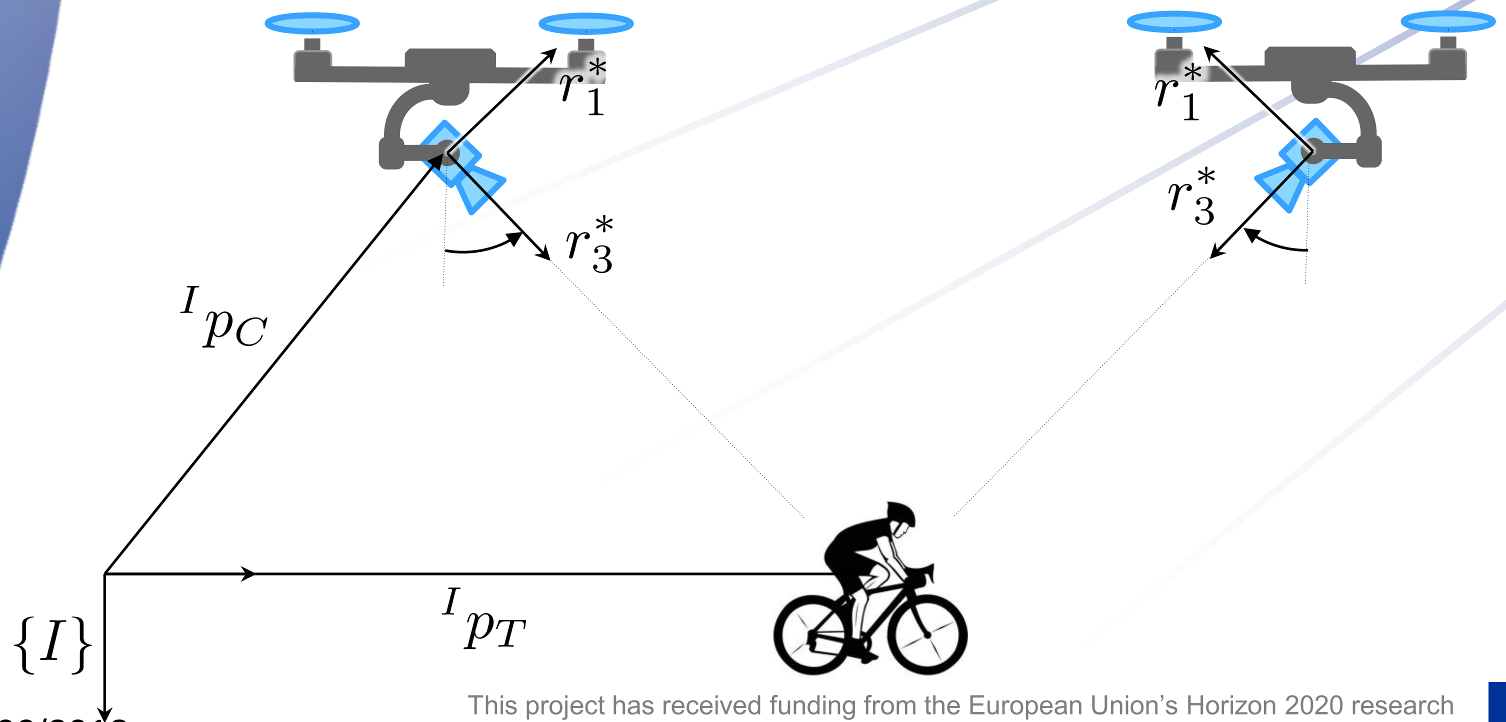
Align with target velocity

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Gimbal control

- Desired orientation

$$ {}^I_C R^* = \begin{bmatrix} r_1^* & r_2^* & r_3^* \end{bmatrix} \in \mathbb{SO}(3) $$



Extra degree of freedom
1st alternative

$$ r_2^* = \frac{r_3^* \times e_3}{\| r_3^* \times e_3 \|} $$

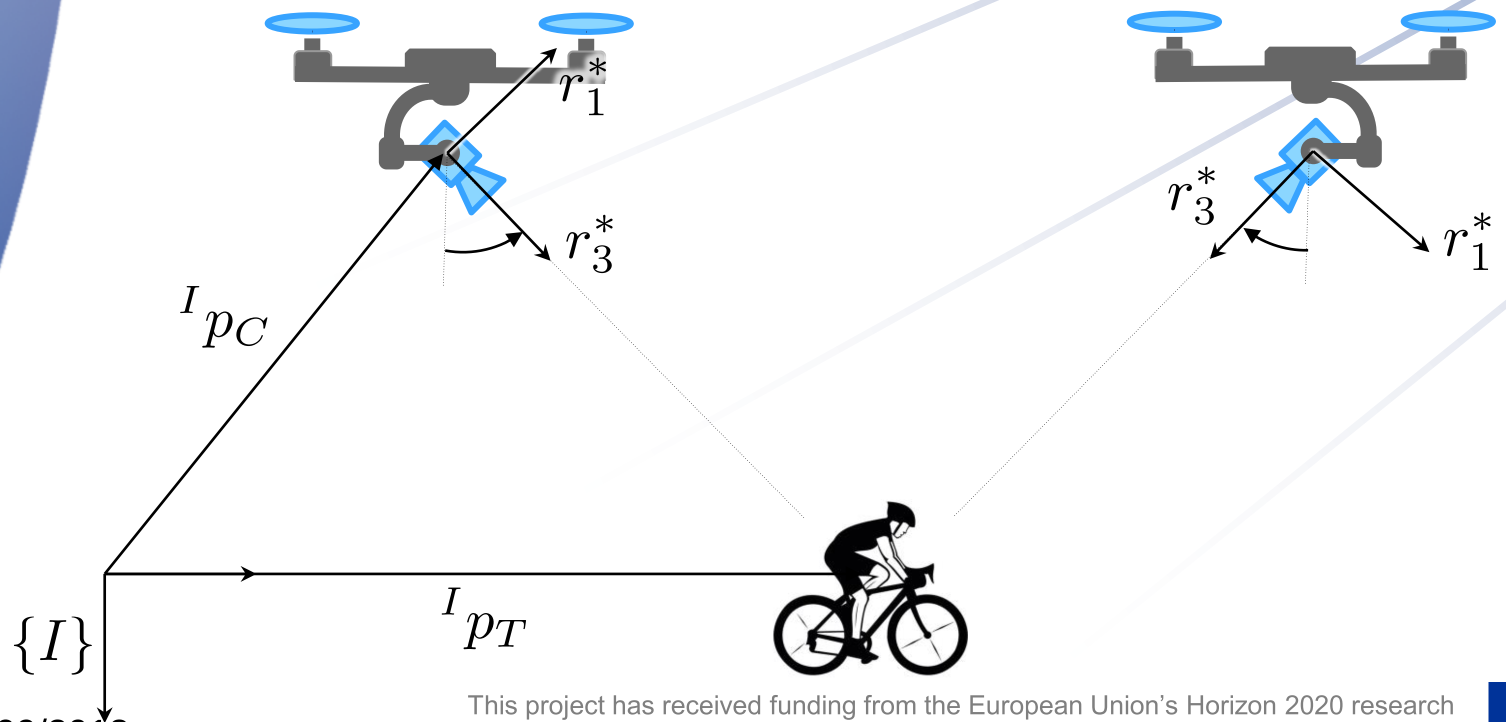
$$ r_1^* = r_3^* \times r_2^* $$

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Gimbal control

- Desired orientation

$$ {}^{I}_{C}R^{*} = \begin{bmatrix} r_1^* & r_2^* & r_3^* \end{bmatrix} \in \mathbb{SO}(3) $$



Extra degree of freedom
2nd alternative

$$ r_1^* = \Pi_{r_3^*} v_T $$

More suitable for fly-overs

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Gimbal control

- Desired orientation: ${}^{I}_{C}R^* = \begin{bmatrix} r_1^* & r_2^* & r_3^* \end{bmatrix} \in \mathbb{SO}(3)$
- Current orientation: ${}^{C}_{I}R \in \mathbb{SO}(3)$
- Error: $R_e = R^T R^*$
- Nonlin w: $\omega = \omega^* + k\,S^{-1}(R_e - R_e^T)$

$$\omega = \omega^* + kS^{-1}(R_e - R_e^T)$$

$\downarrow$

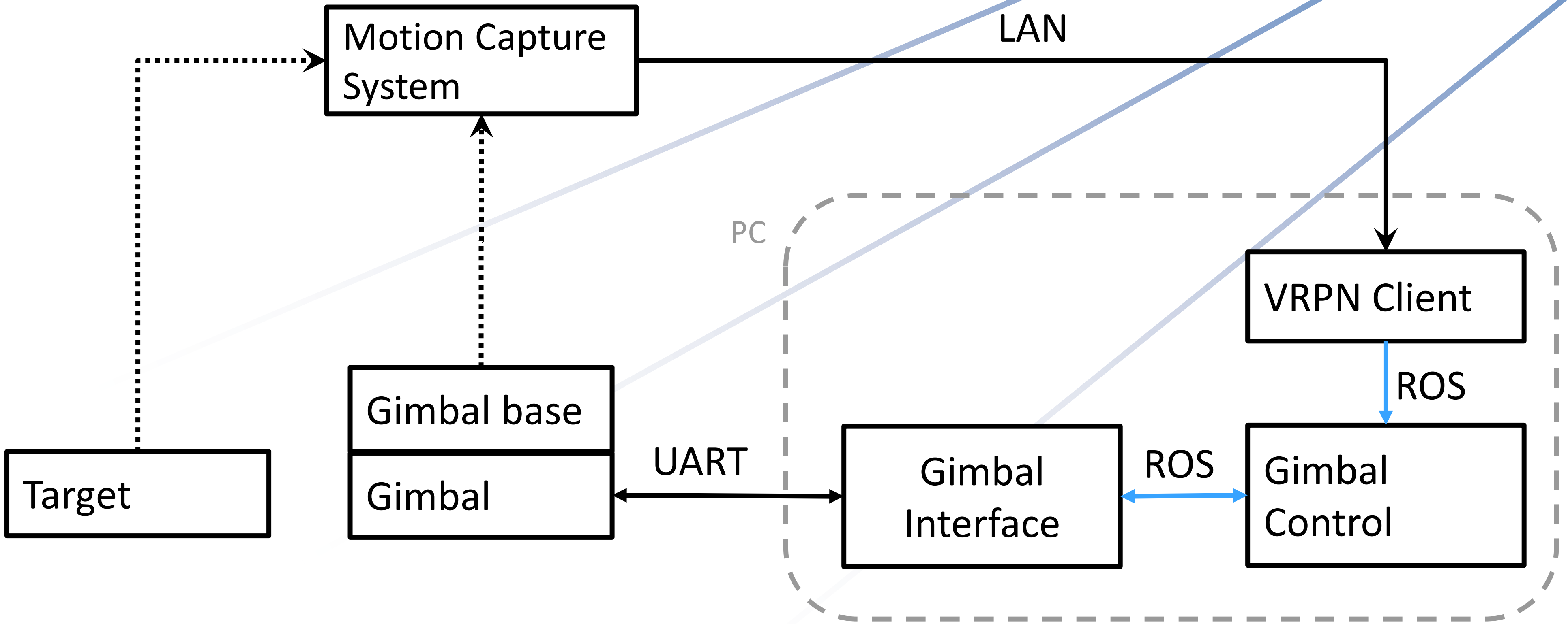
Feed-forward term: target velocity needed

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Gimbal controller – experimental test

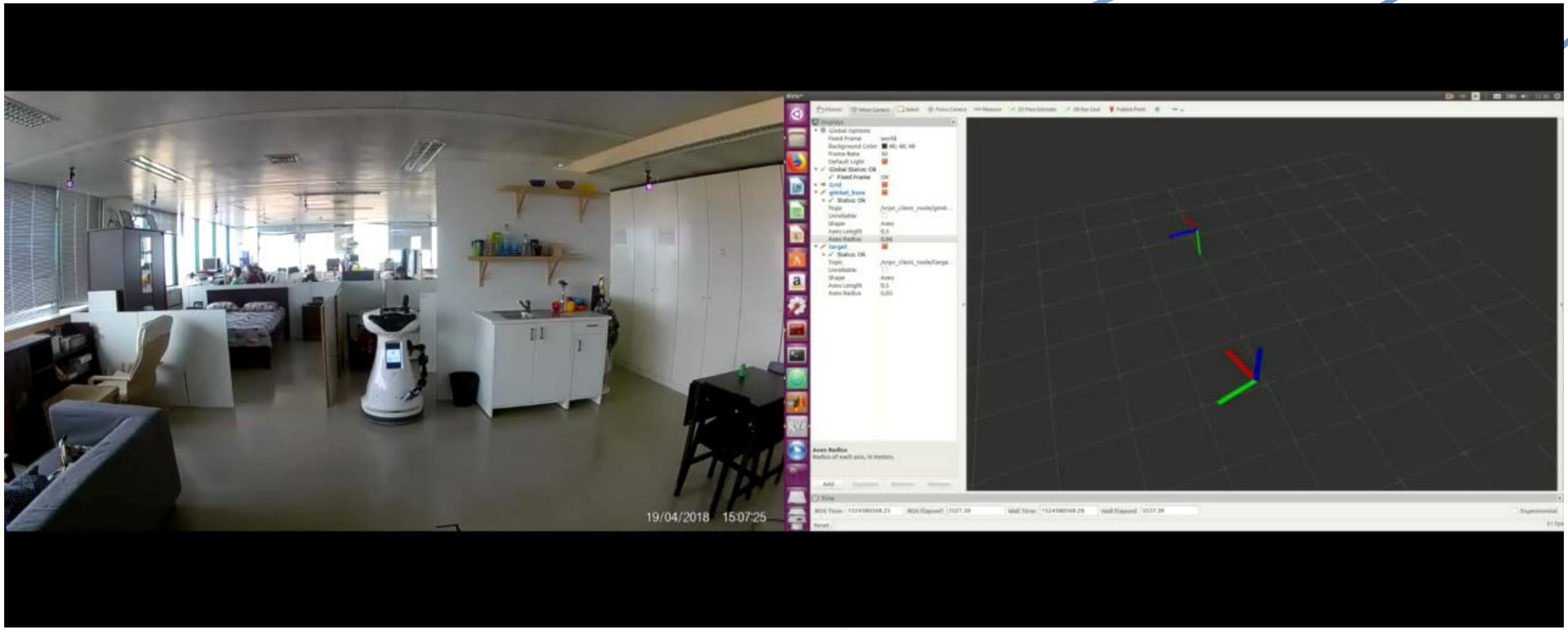
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Gimbal controller – experimental test



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Gimbal controller – experimental tests



14-15/09/2018

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Gimbal controller – experimental test

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Gimbal controller – experimental test

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Drone mission planning and control

- Audiovisual shooting mission definition
- Multiple drone mission planning.
- **Multiple drone mission control:**
  - Single drone flight control.
  - Gimbal control.
  - **BMMCC control.**
  - Multiple drone control architecture.
  - Drone formation control.
  - Collision avoidance.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

BMMCC Control

- No feedback from the camera
- Two ways of mapping the commands to the controls:

Select a particular setting	Increment / decrement
Iris	Zoom
Focus	Start/Stop Recording
Audio	Auto Focus
Frame Rate	ISO
Codec	Shutter Angle
	White Balance

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

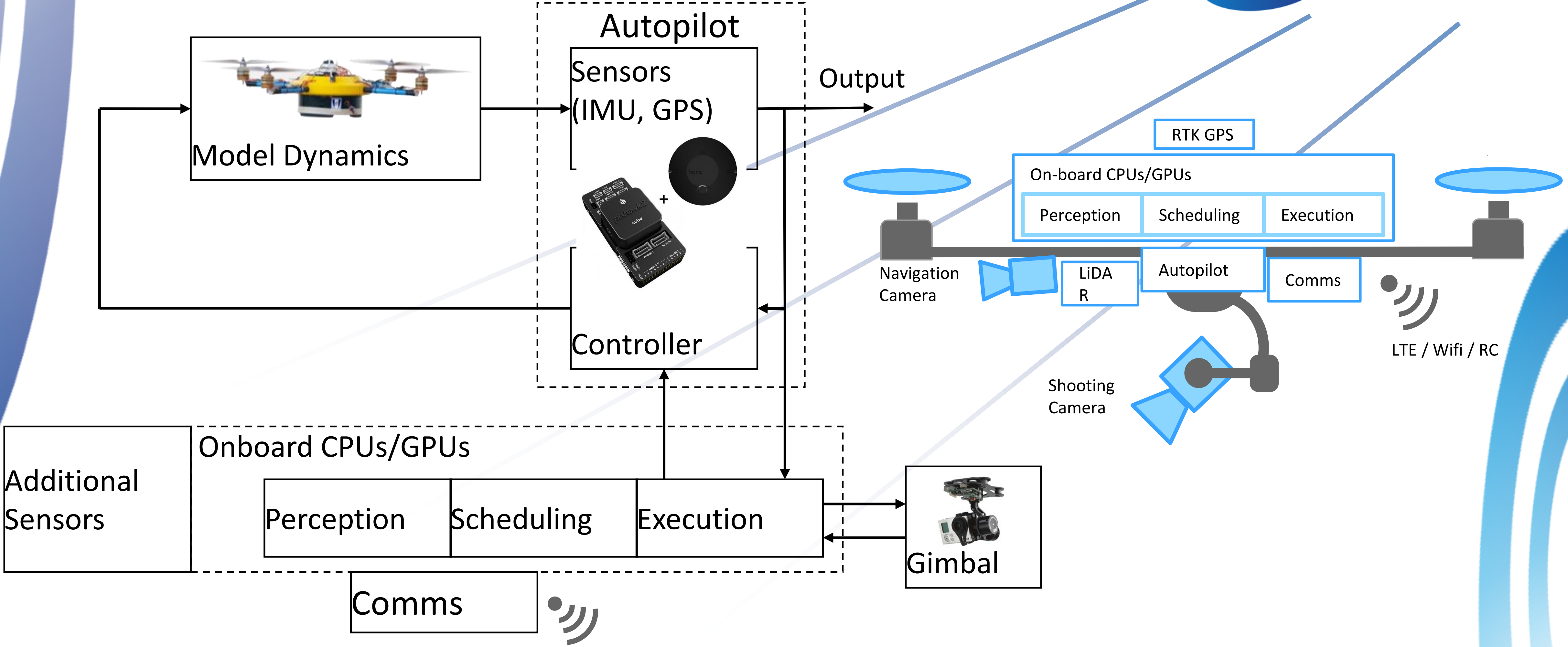
Drone mission planning and control

MultiDrone

- Audiovisual shooting mission definition
- Multiple drone mission planning.
- **Multiple drone mission control:**
  - Single drone flight control.
  - Gimbal control.
  - BMMCC control.
  - **Multiple drone control architecture.**
  - Drone formation control.
  - Collision avoidance.

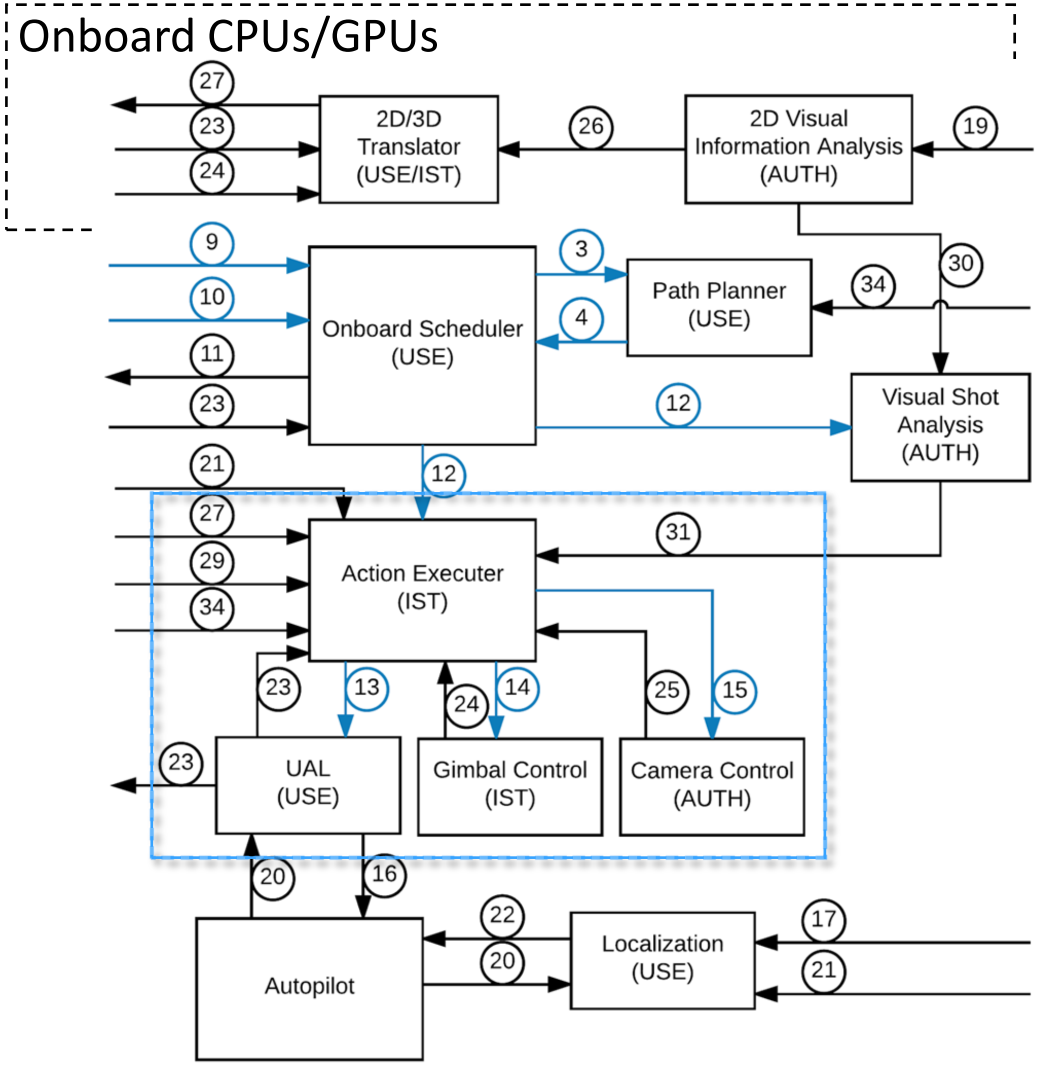
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Multidrone Onboard Architecture



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Onboard functional architecture



1	Shooting Mission	18	Navigation camera
2	Request plan	19	Shooting camera
3	Request path	20	Drone telemetry
4	Computed path	21	Geometric map
5	Mission plan	22	Drone localization
6	Safety check	23	Drone position
7	Plan status	24	Gimbal status
8	Director events	25	Camera status
9	Events	26	Target position (2D)
10	Drone actions	27	3D Target position (from drone)
11	Drone status	28	3D Target position (from target)
12	Action controllers	29	3D Target position
13	Control commands	30	Visual information
14	Gimbal control	31	Visual control errors
15	Camera control	32	Annotated images
16	Drone control	33	Semantic annotations
17	LIDAR	34	Semantic map
→	Topics	→	Services

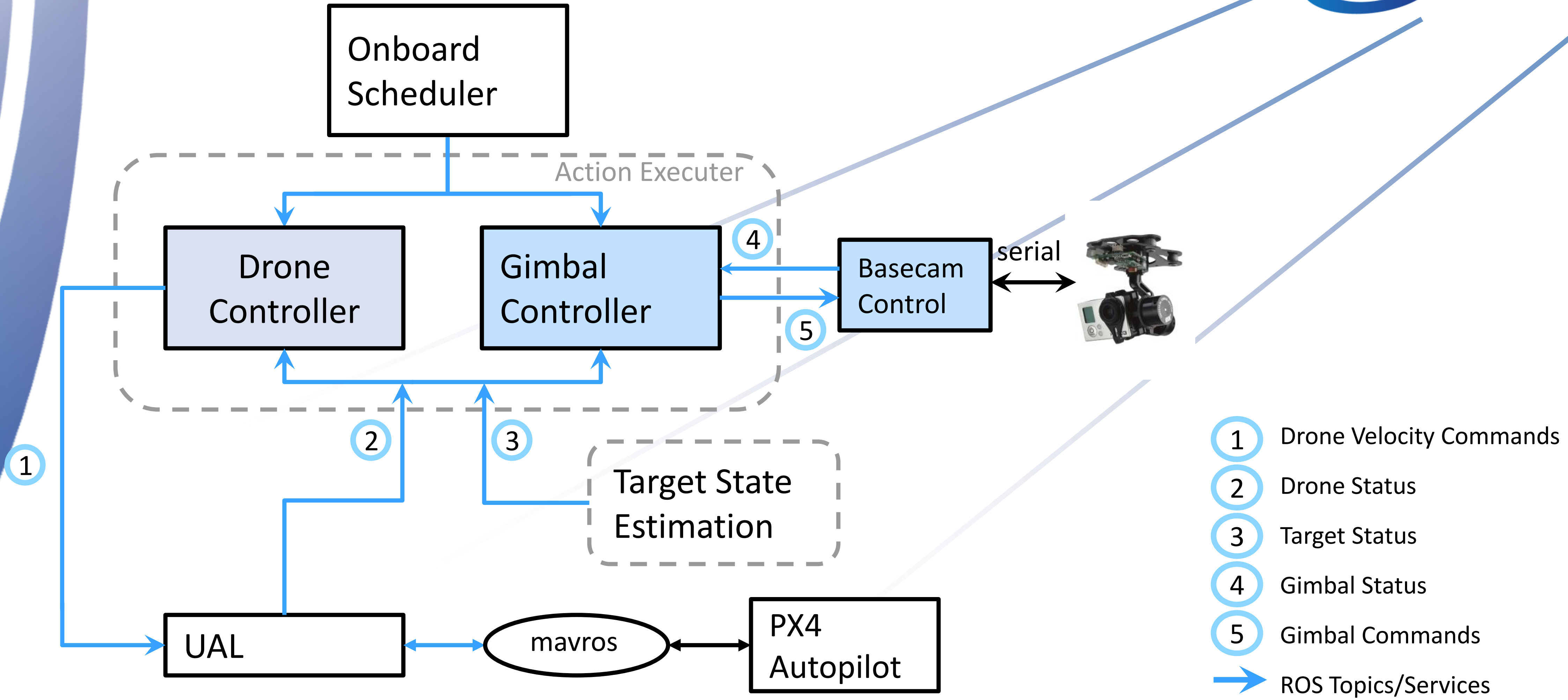
Action Execution

- Onboard Scheduler activates execution of individual drone actions.
  - *Navigation Actions*: Take-off, Land, Go to Waypoint, etc.
  - *Shooting Actions (SA)*: Lateral Tracking, Chase, Still, Orbit, etc.

Shooting actions involve drone control + gimbal control for target tracking.

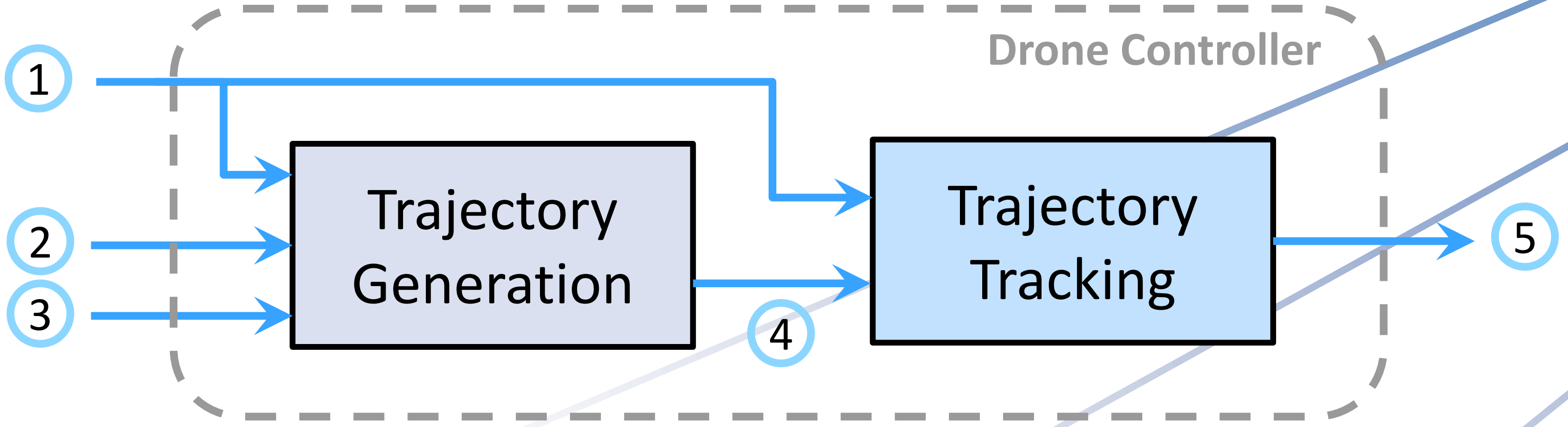
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Action Execution



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Drone Controller



1. Drone Status
2. Target Status
3. Shooting Action parameters
4. Reference
5. Drone Velocity Command

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Drone mission planning and control

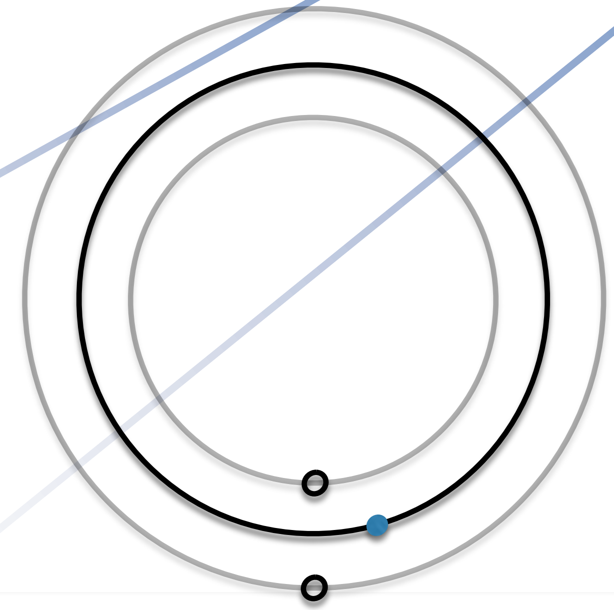
MultiDrone

- Audiovisual shooting mission definition
- Multiple drone mission planning.
- **Multiple drone mission control:**
  - Single drone flight control.
  - Gimbal control.
  - BMMCC control.
  - Multiple drone control architecture.
  - **Drone formation control.**
  - Collision avoidance.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Leader-following for formation control

- Main idea:
  Trailer-like behavior for the followers.



In inertial frame:
Translated identical paths

In trailer frame:
Different paths, no superposition

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

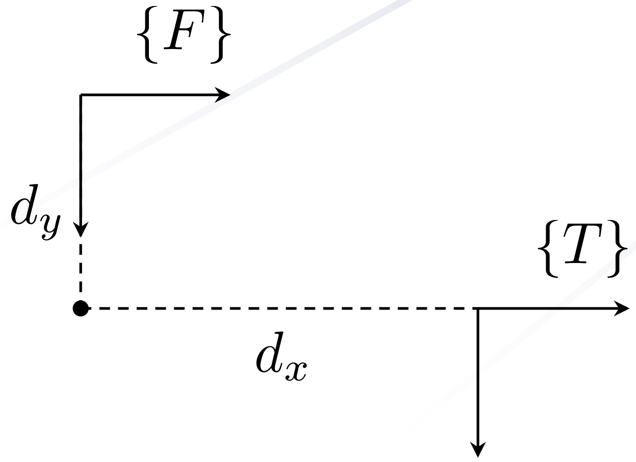
Trailer approach in 2D

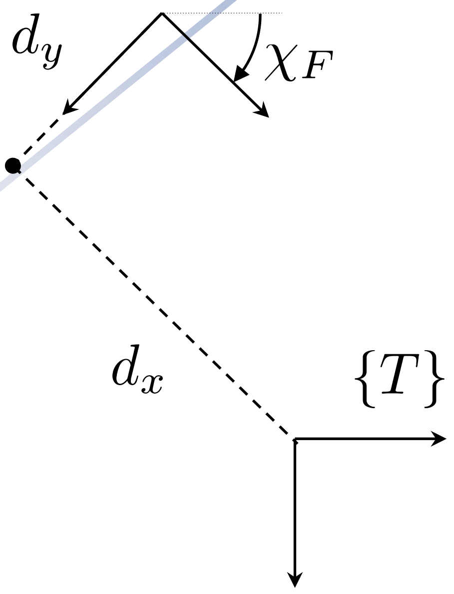
F – Follower

T – Target

$$p_F = p_T - R_z(\chi_F)\begin{bmatrix} d_x & d_y \end{bmatrix}^T$$

$$\begin{bmatrix} x_F \\ y_F \end{bmatrix} = \begin{bmatrix} x_T \\ y_T \end{bmatrix} - \begin{bmatrix} \cos(\chi_F) & -\sin(\chi_F) \\ \sin(\chi_F) & \cos(\chi_F) \end{bmatrix}\begin{bmatrix} d_x \\ d_y \end{bmatrix}$$





This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

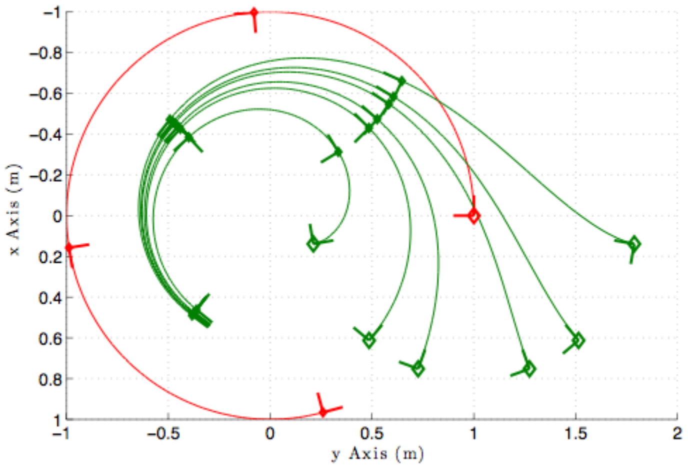
Trailer approach in 2D

F – Follower

T – Target

$$p_F = p_T - R_z(\chi_F)\begin{bmatrix} d_x & d_y \end{bmatrix}^T$$

$$\begin{bmatrix} x_F \\ y_F \end{bmatrix} = \begin{bmatrix} x_T \\ y_T \end{bmatrix} - \begin{bmatrix} \cos(\chi_F) & -\sin(\chi_F) \\ \sin(\chi_F) & \cos(\chi_F) \end{bmatrix} \begin{bmatrix} d_x \\ d_y \end{bmatrix}$$



$(p_T, \dot{p}_T)$ Target position & velocity → **Trajectory generation** → p_F Desired Follower Position

(d_x, d_y) Distance parameters → **Trajectory generation**

$$\dot{\chi}_F = -\frac{\|\dot{p}_T\|}{d_x}\sin(\chi_F - \chi_T)$$

$$p_F = p_T - R_z(\chi_F)\begin{bmatrix} d_x & d_y \end{bmatrix}^T$$

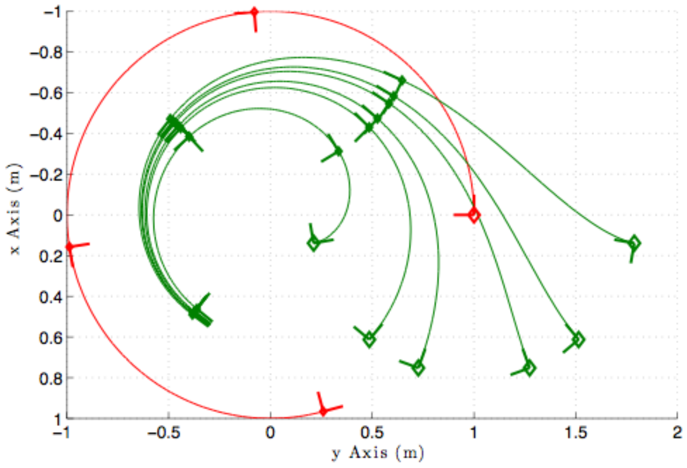
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

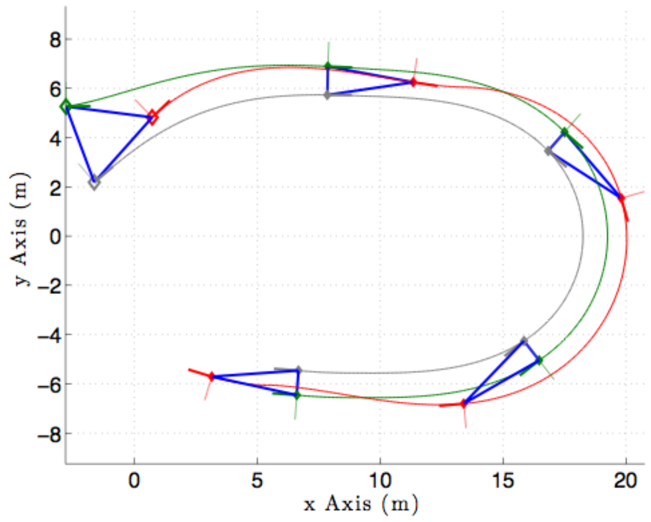
Properties

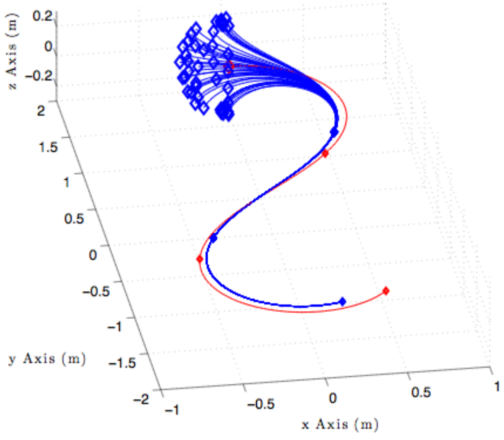
Trailer-like behaviour

- Different initial conditions, same asymptotic behavior

- Convergence to a rigid formation
- Both in 2D and 3D
- On-the-fly computation



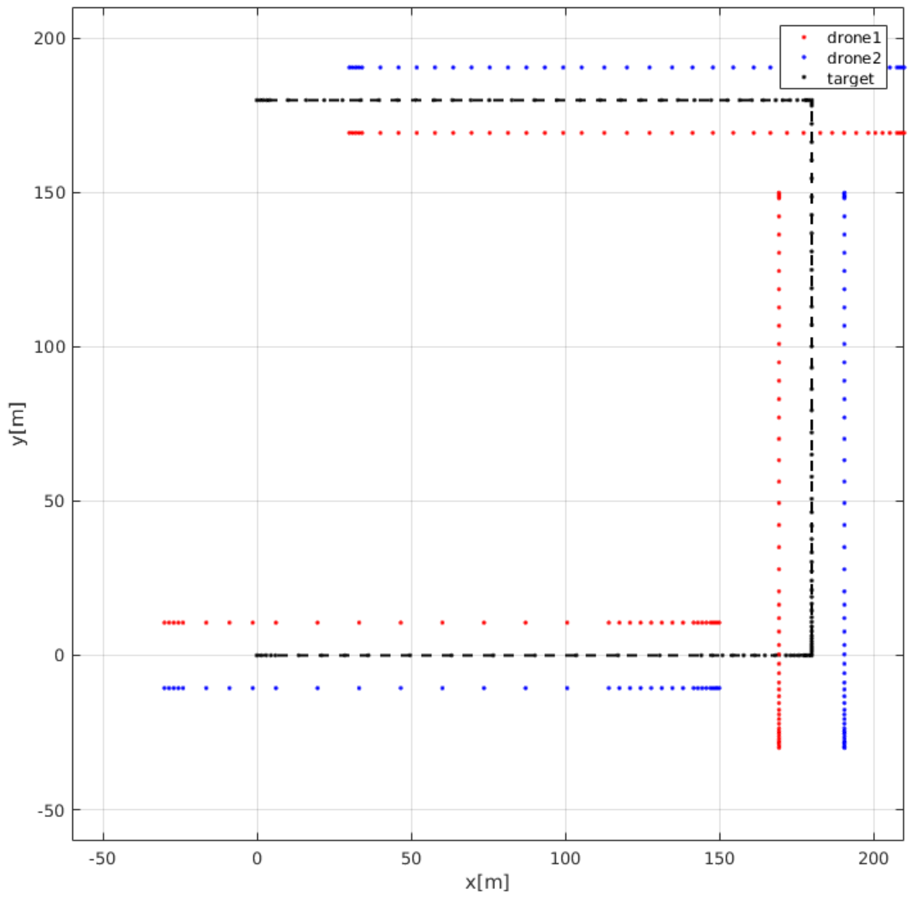




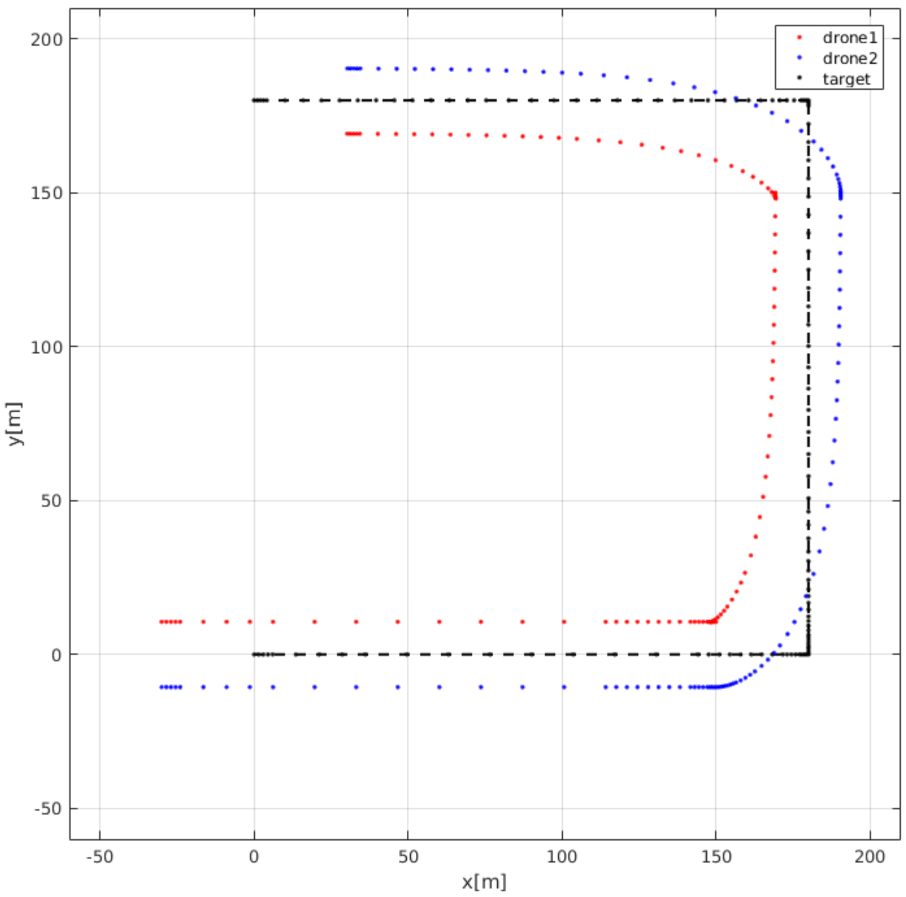
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Trailer approach properties

Without Trailer



With Trailer

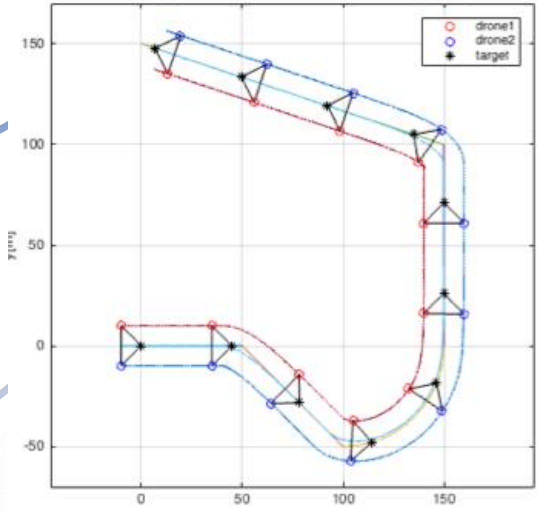


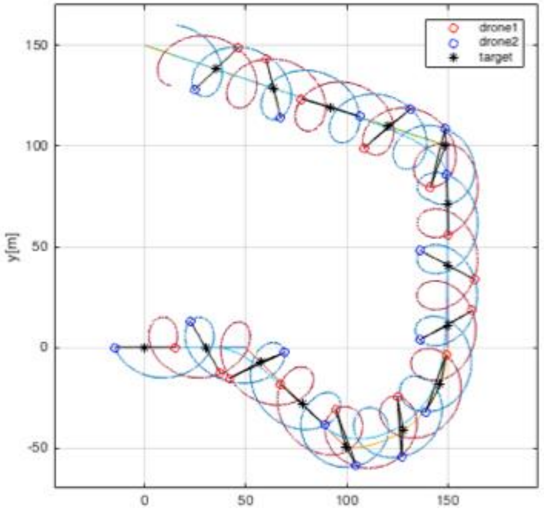
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Drone Formation Control

- Shooting Actions (SA) for Target Tracking
  Trailer approach.

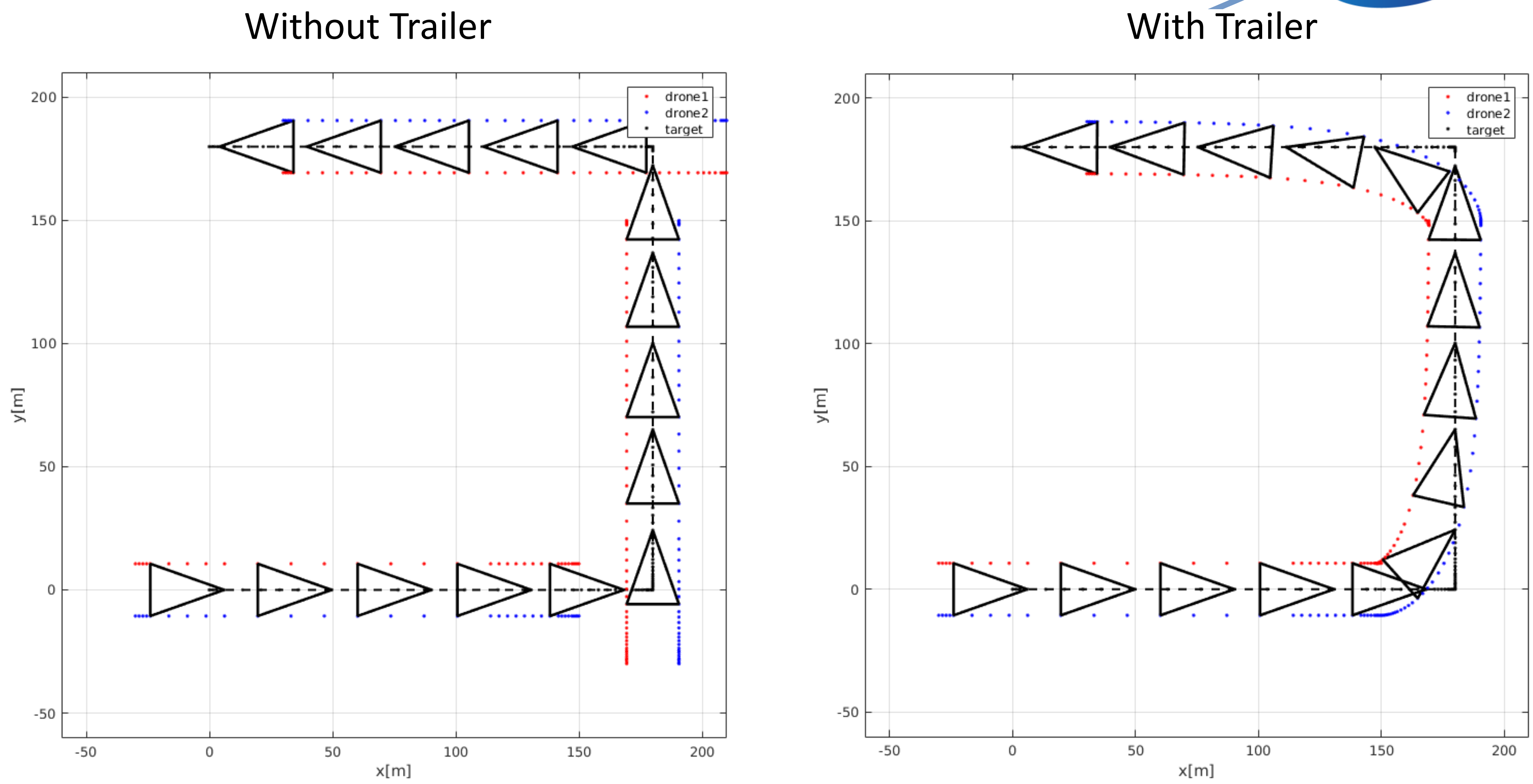
- Examples:
  SA1 – constant relative positions
  SA2 – Orbit trajectory
  SA3 – lateral tracking and top view





This project has received funding from the European Union's Horizon 2020 research
and innovation programme under grant agreement No 731667 (MULTIDRONE)

Trailer approach properties

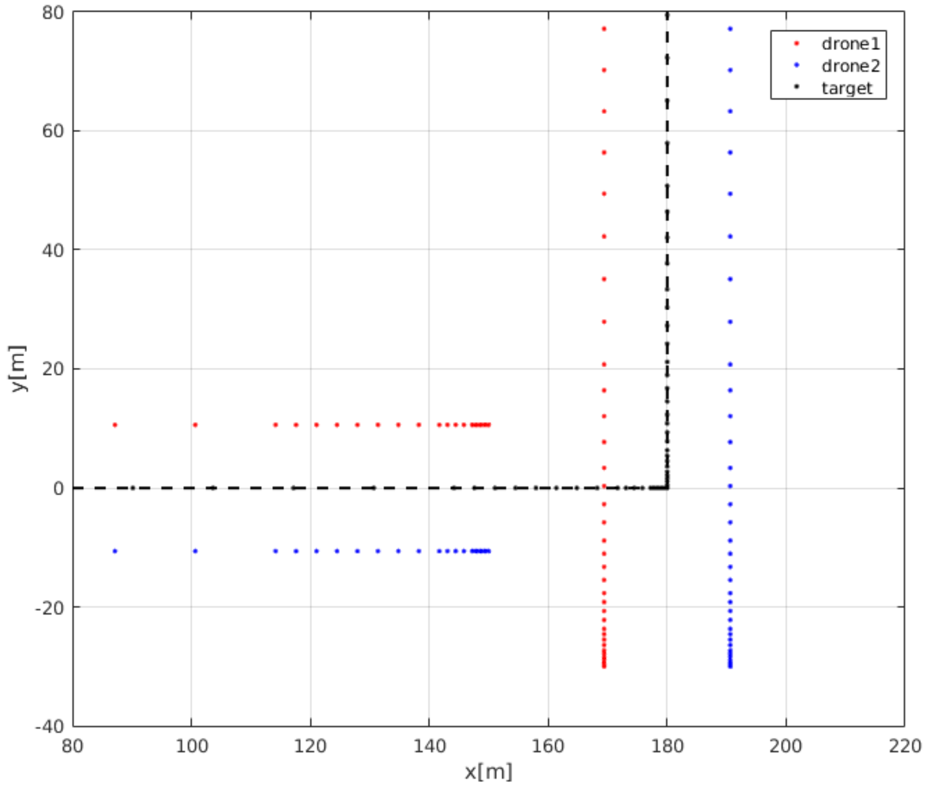


14-15/09/2018

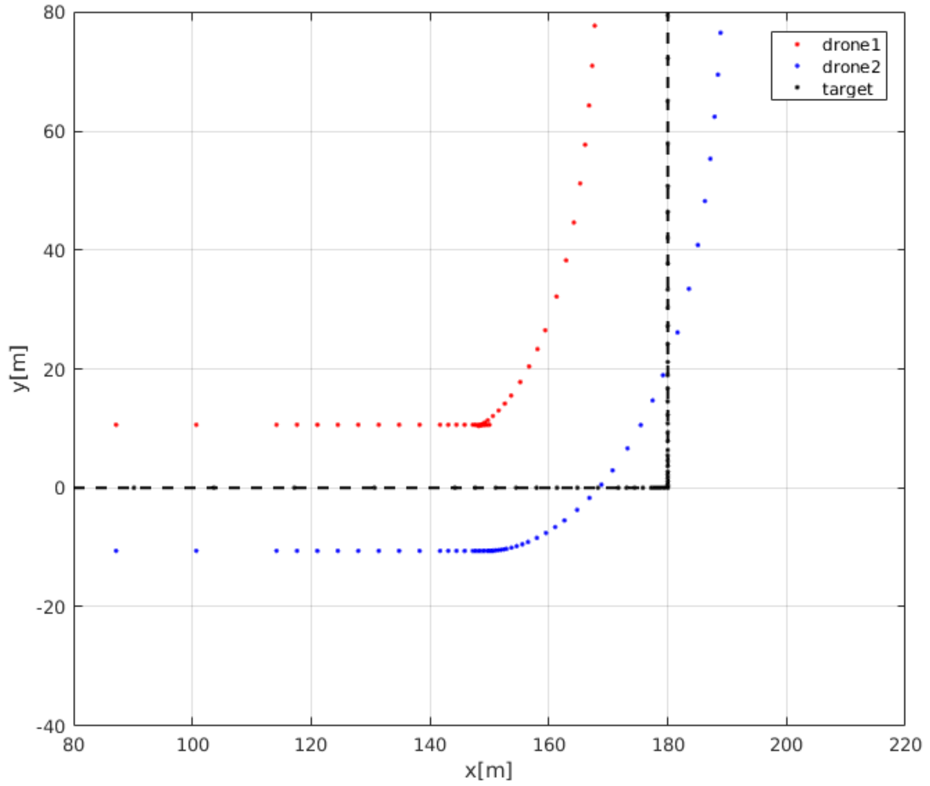
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Trailer approach properties

Without Trailer



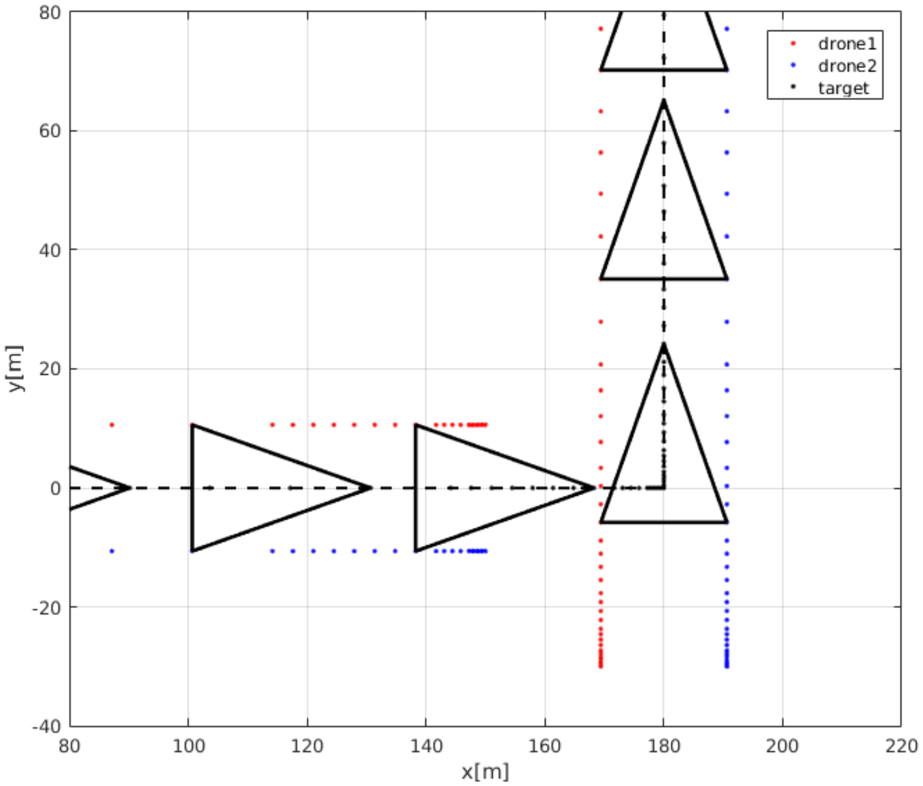
With Trailer



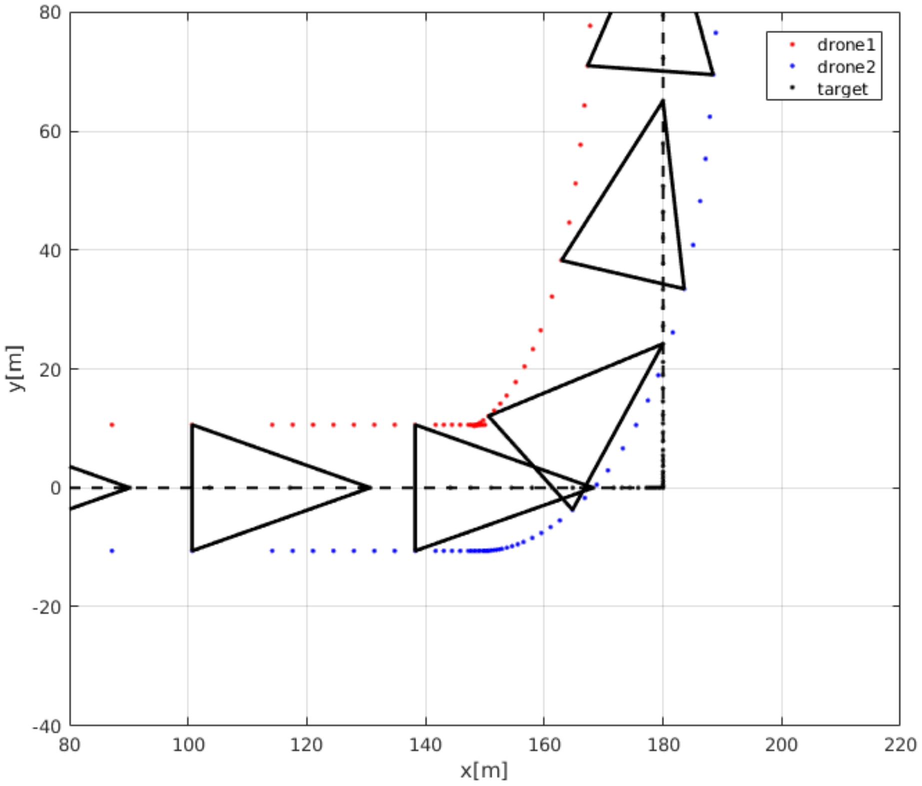
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Trailer approach properties

Without Trailer



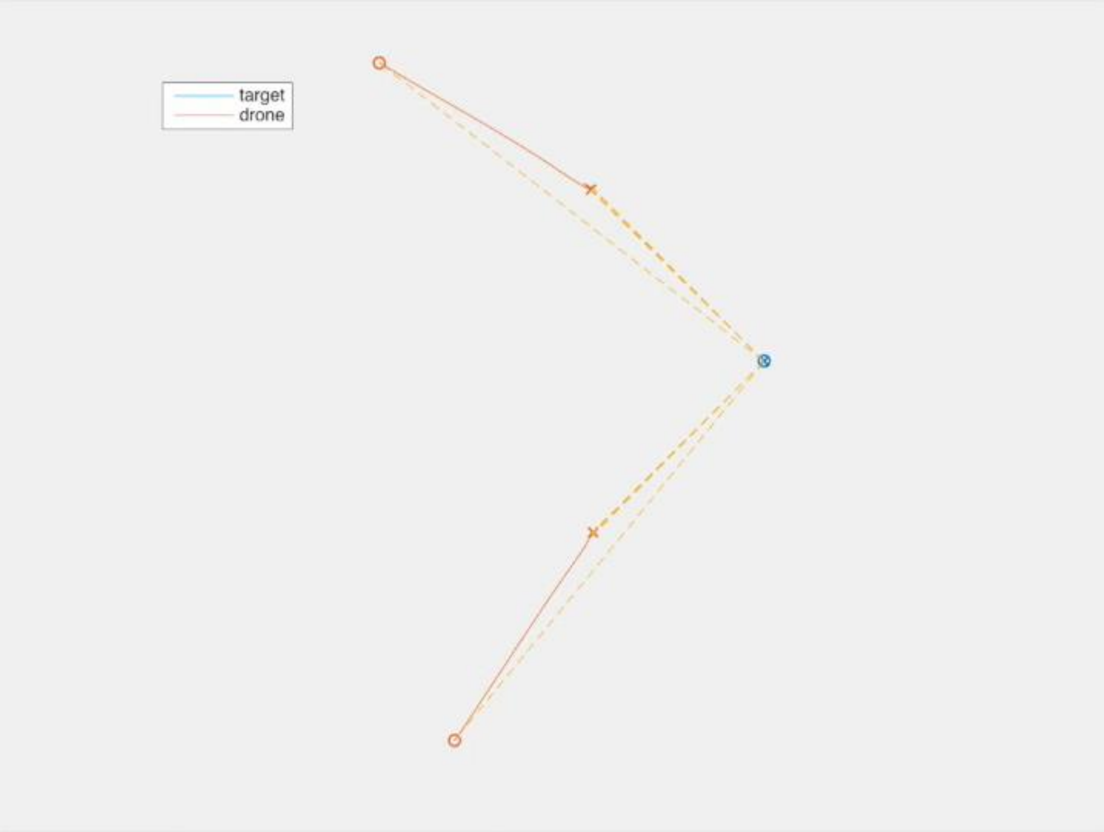
With Trailer



14-15/09/2018

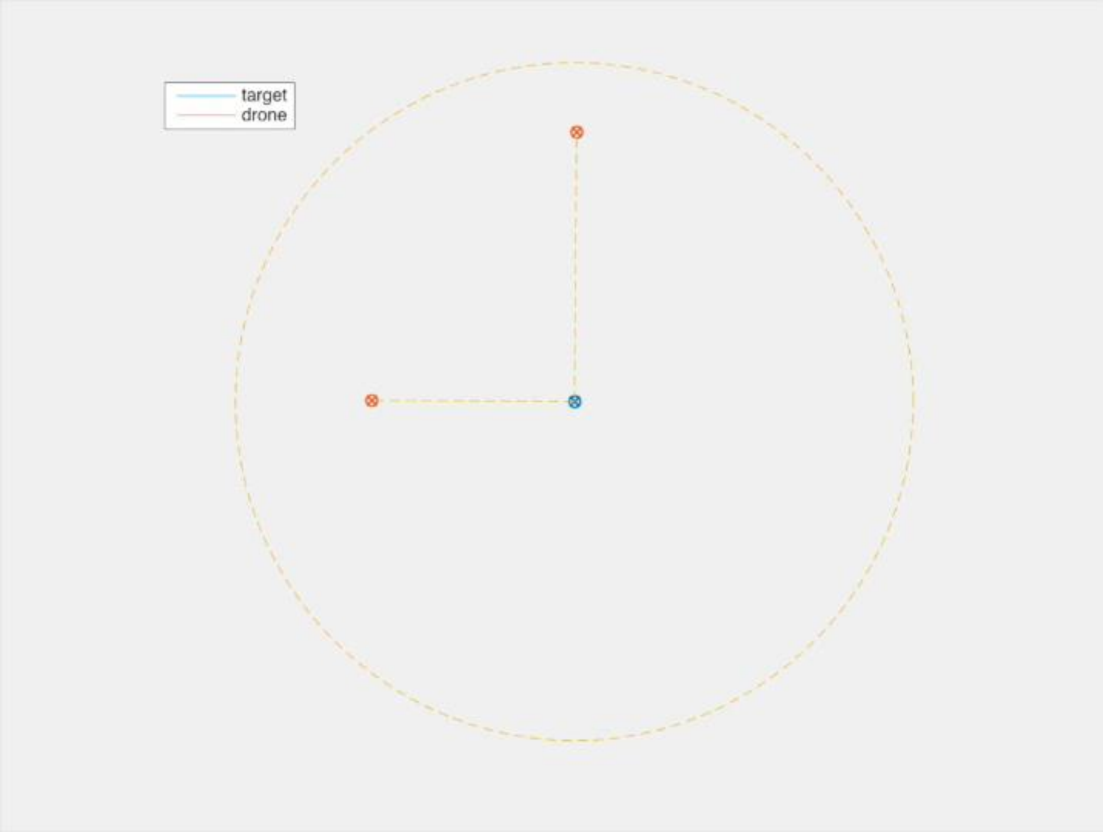
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

SA1 - Constant relative positions



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

SA2 - Orbit trajectory



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

SA3 – Lateral tracking and top view

14-15/09/2018

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Drone mission planning and control

MultiDrone

- Audiovisual shooting mission definition.
- Multiple drone mission planning.
- **Multiple drone mission control:**
  - Single drone flight control.
  - Gimbal control.
  - BMMCC control.
  - Multiple drone control architecture.
  - Drone formation control.
  - **Collision avoidance.**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Multi-drone Conflict Resolution Problem Definition

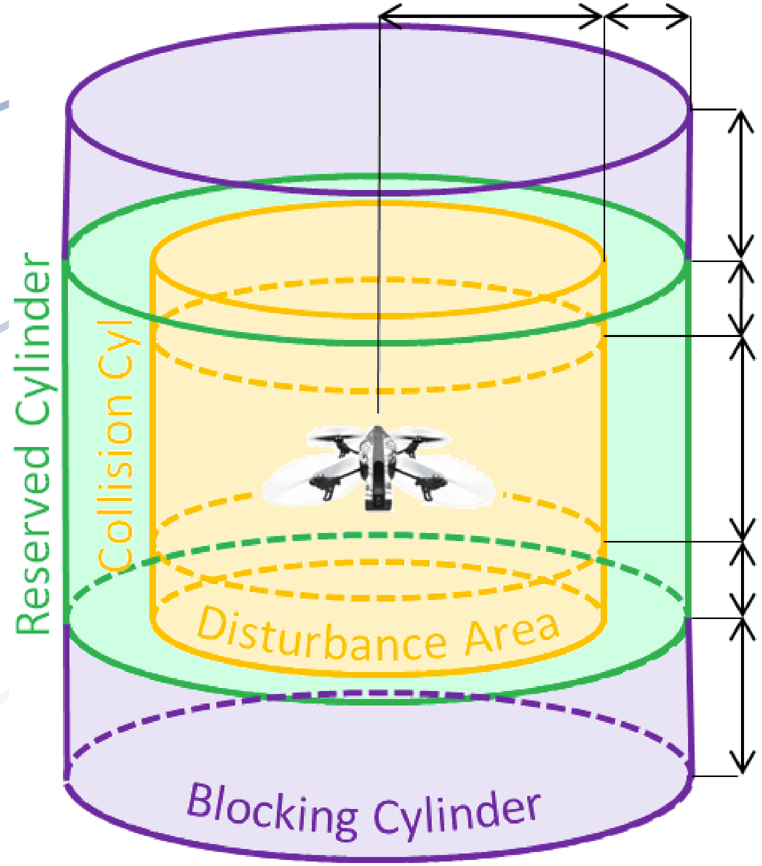
MultiDrone

- Navigate a team of drones in a shared 3D space without collision.
- Starting configuration to a goal configuration.
- Drones must detect and resolve conflicts in a decentralized manner.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Decentralized 3D collision avoidance

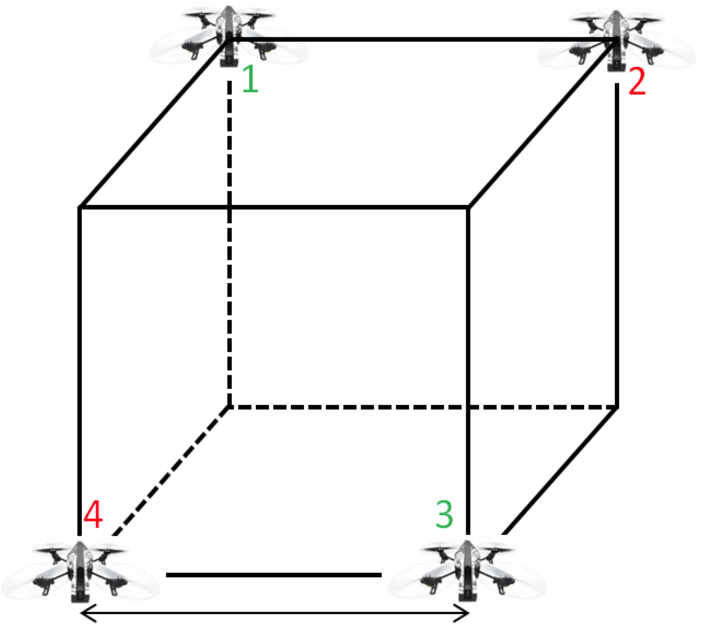
- Collision hull defined as a cylinder (yellow).
- Horizontal conflict when reserve.d cylinder (green) overlaps with others.
- Vertical conflict when blocking cylinder overlaps with others.
- Cylinders allow drones to brake on time and maneuver to avoid collision.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

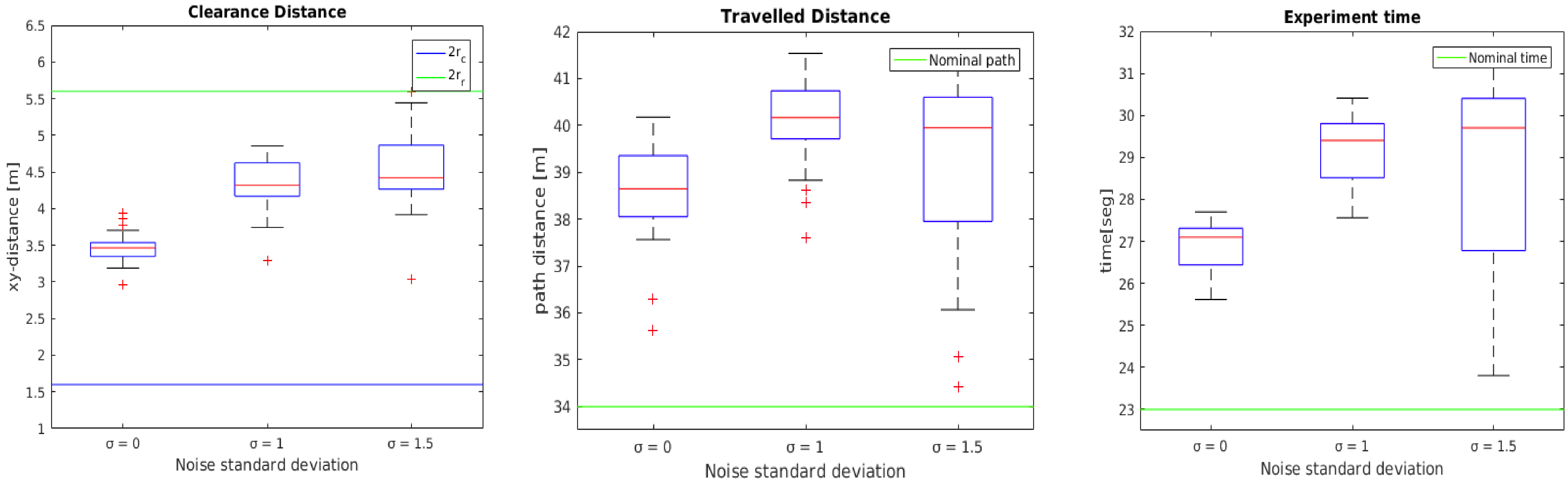
SITL Simulations

- Simulations with a SITL scheme. Noisy GPS measurements.
- Drones in cube exchanging positions.
- Drones in conflict surround each other creating a virtual roundabout.
- Clearance level: minimum distance of each drone to its nearest neighbor.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

SITL Simulations



- Clearance does not decrease with noise. Reserved cylinders overleap but not collision ones.
- Travelled distance and time do not significantly increase with noise.
- Algorithm is robust against noisy position measurements.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Results

- Preliminary field flights started.
- Drones braking distances quite sensitive to wind.
- Next steps:
  - Integrate sensors for obstacle detection
  - Control drones' orientation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)

Q & A

Thank you very much for your attention!

Contact: Prof. I. Pitas
pitas@aiia.csd.auth.gr
www.multidrone.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731667 (MULTIDRONE)