Multiple Drone Mission Planning and Control summary

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Artificial Intelligence & Information Analysis Lab

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Multiple Drone Mission Planning and Control

- Multiple drone mission planning.
  - Audiovisual shooting mission definition.
  - Mission Planning Vocabulary.
  - High-level planning.
  - Path planning.
- Manual drone operation/control.
- Automatic drone mission control.
  - Single drone flight control.
  - Gimbal and camera control.
  - Multiple drone control architecture.
  - Drone formation control.
  - Collision avoidance.
  - Vision-based single drone control.

Drone mission planning and control: Objectives

- **High-level drone mission planning**
  - **XML language** to describe drone missions.
  - **Plans** for mission task assignment to drones, taking into account safety (no-fly zones) and resources (battery level).
- Multiple-drone misión execution
  - **Re-planning** after unexpected events (e.g., drone emergency, new tasks).
  - Multiple-drone **formation control** for mission execution.
  - **Target tracking** (for specific missions, e.g., AV shooting).

Drone mission planning and control: Objectives

- Multiple drone ***safety*** and ***robustness***:
  - Safe path planning**.**
  - Multiple-drone ***collision avoidance.***
  - Contigency plans for emergencies.

Drone mission planning and control

- **Special case: Audiovisual shooting mission definition.**
- Multiple drone mission planning.
- Multiple drone mission control based on 3D state:
  - Single drone flight control.
  - Gimbal and camera control.
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Mission Planning Vocabulary

- Multiple drone ***Mission***: list of multiple ***actions*** developing over time.
- Example: ***AV shooting mission*.**
- 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, …

Mission Planning Vocabulary

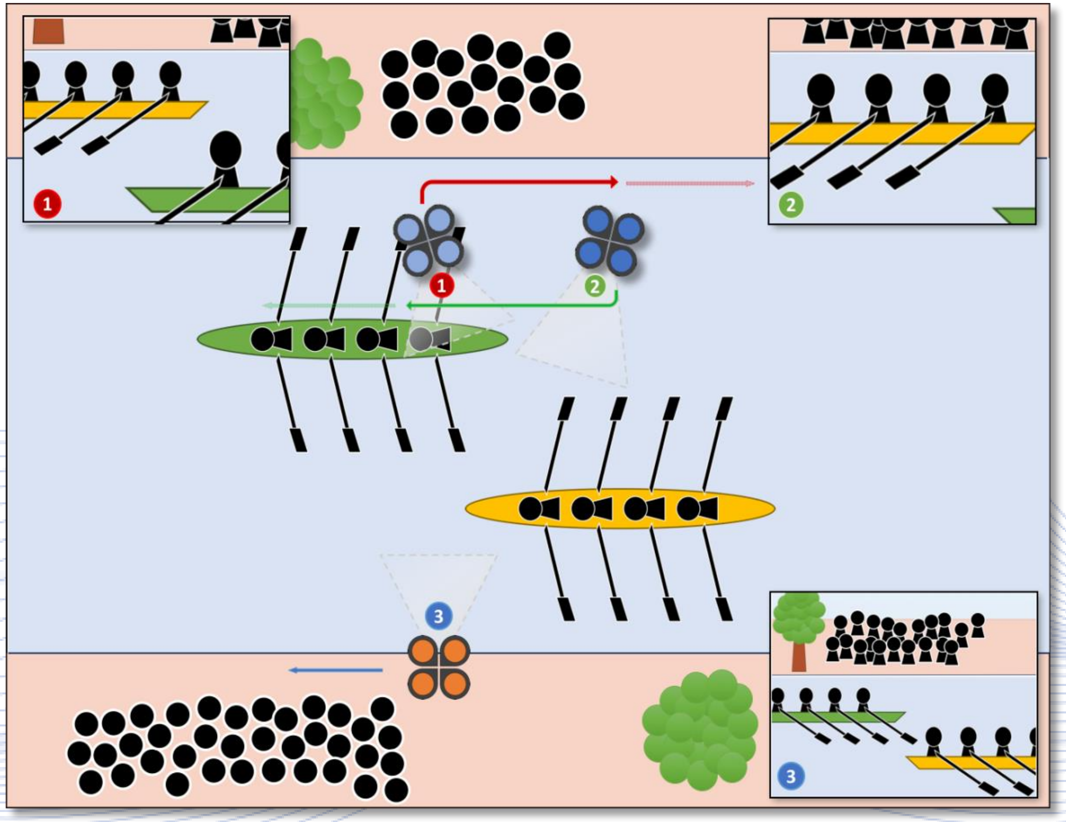
- Shooting Actions are ***event-triggered***:
  - A start event is associated to each Shooting Action, which will trigger the action when it occurs.
  - E.g., target reaches a milestone, start of race, …

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.

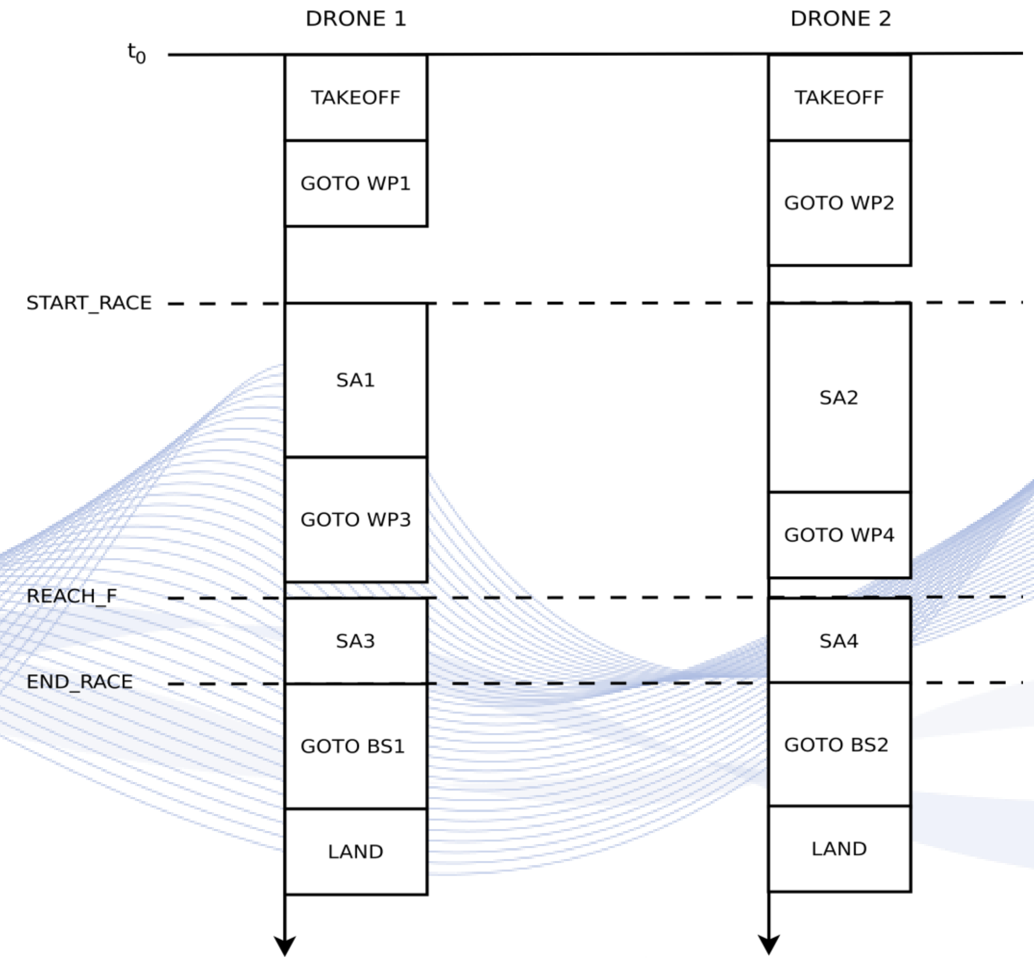
AV Shot types

Example mission: Boat race scenario



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).



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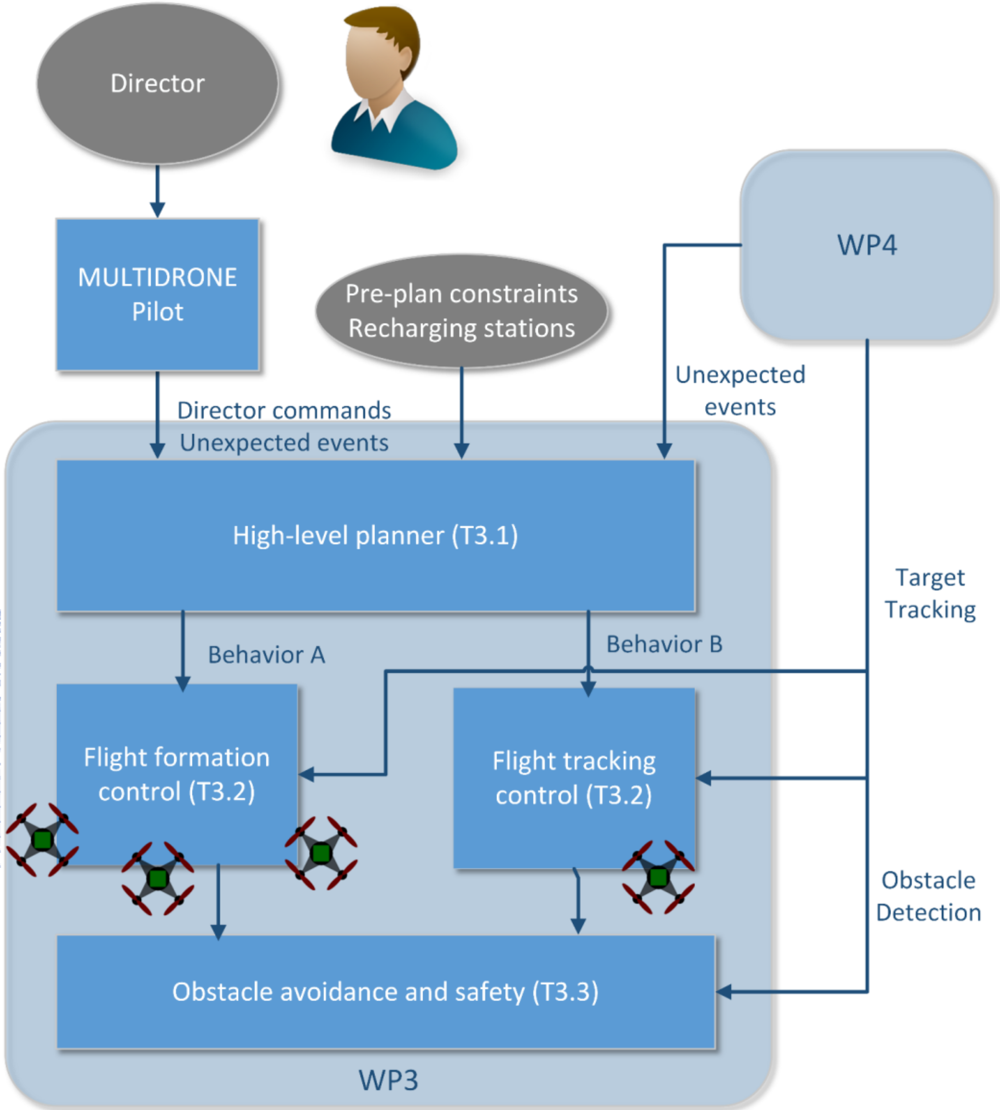
High-level pre-production/production mission planning

- ***High-level planner*** assigns different behaviours/tasks to the multiple-drone team according to director and environmental requirements.

- The multiple-drone planner needs to be ***scalable*** with multiple actors, since on-line re-planning could be needed as events happen or execution is performed.



High-level planning

XML Shooting mission

- Defined by the Dashboard.

List of shooting actions

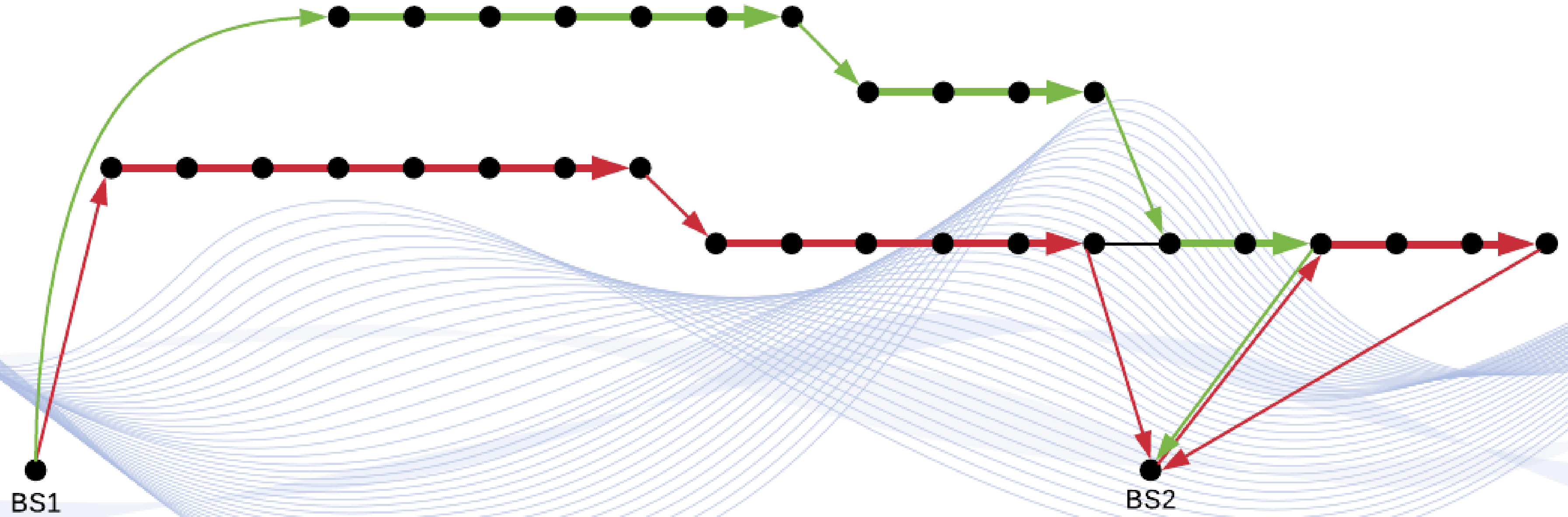
- With triggering events.

High level tasks

- With start location, start time and duration.

Example

- 2 drones covering 4 tasks.
- Some tasks could not be filmed entirely.



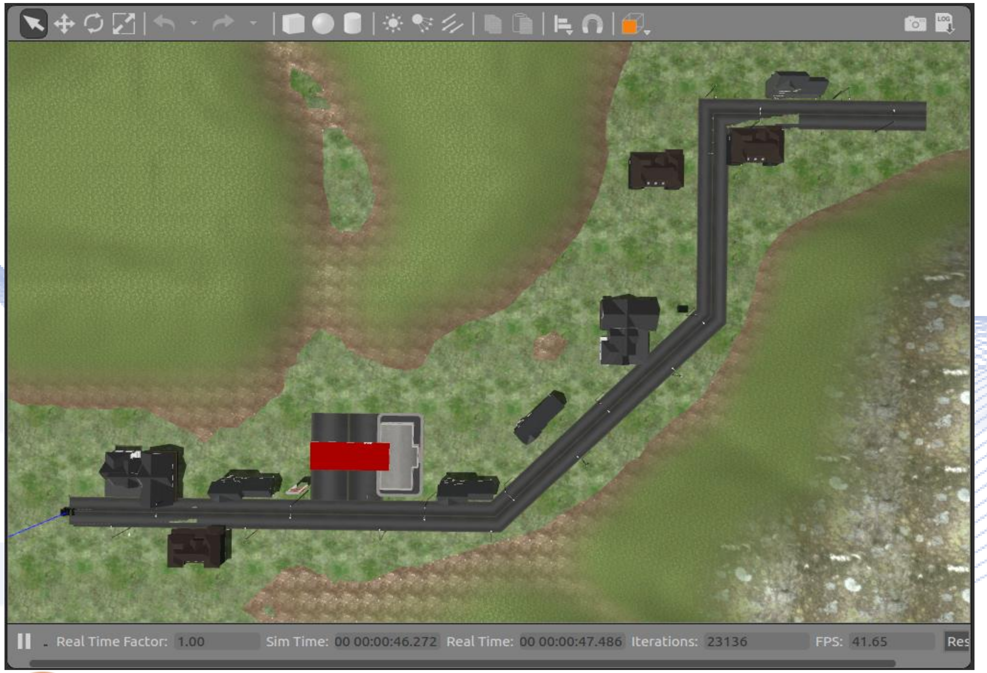
Path Planner

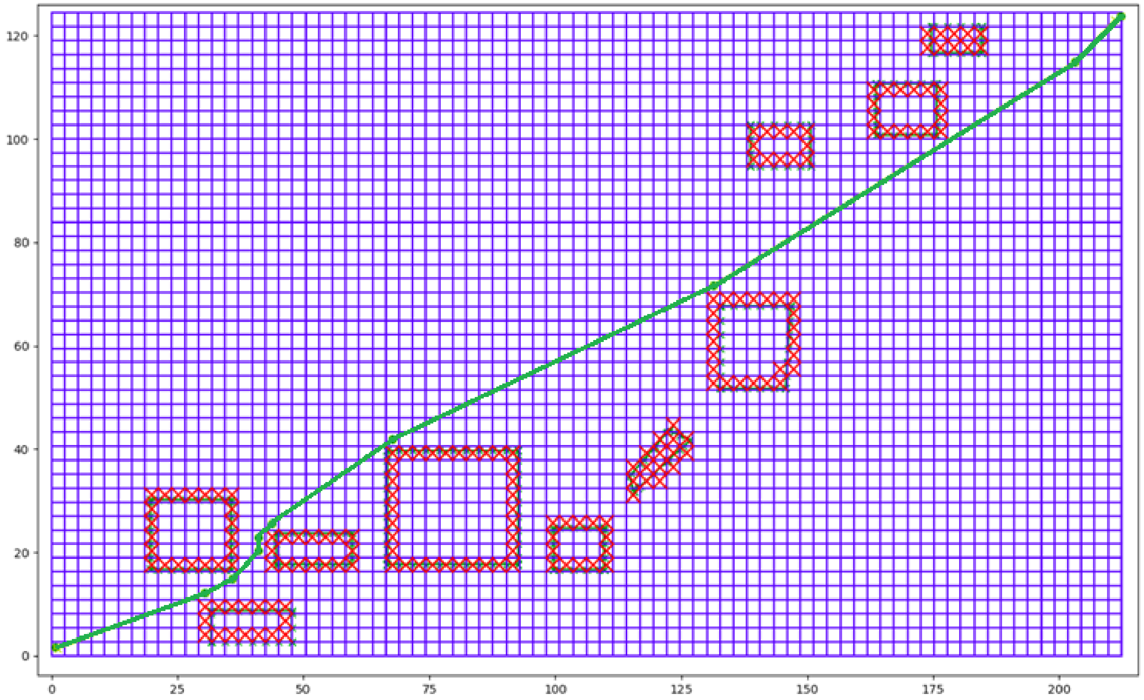
- This submodule is used by:
  - High-level Planner to estimate drone paths and flying times.
  - On-board Scheduler to compute landing path in case of emergency.

- Safe path computed using ***A* search algorithm***:
  - Fast for simple solution spaces.
  - Navigation map implemented as a grid.
  - Semantic annotations are indicated as KML features.
  - No-fly polygons become occupied cells in grid.

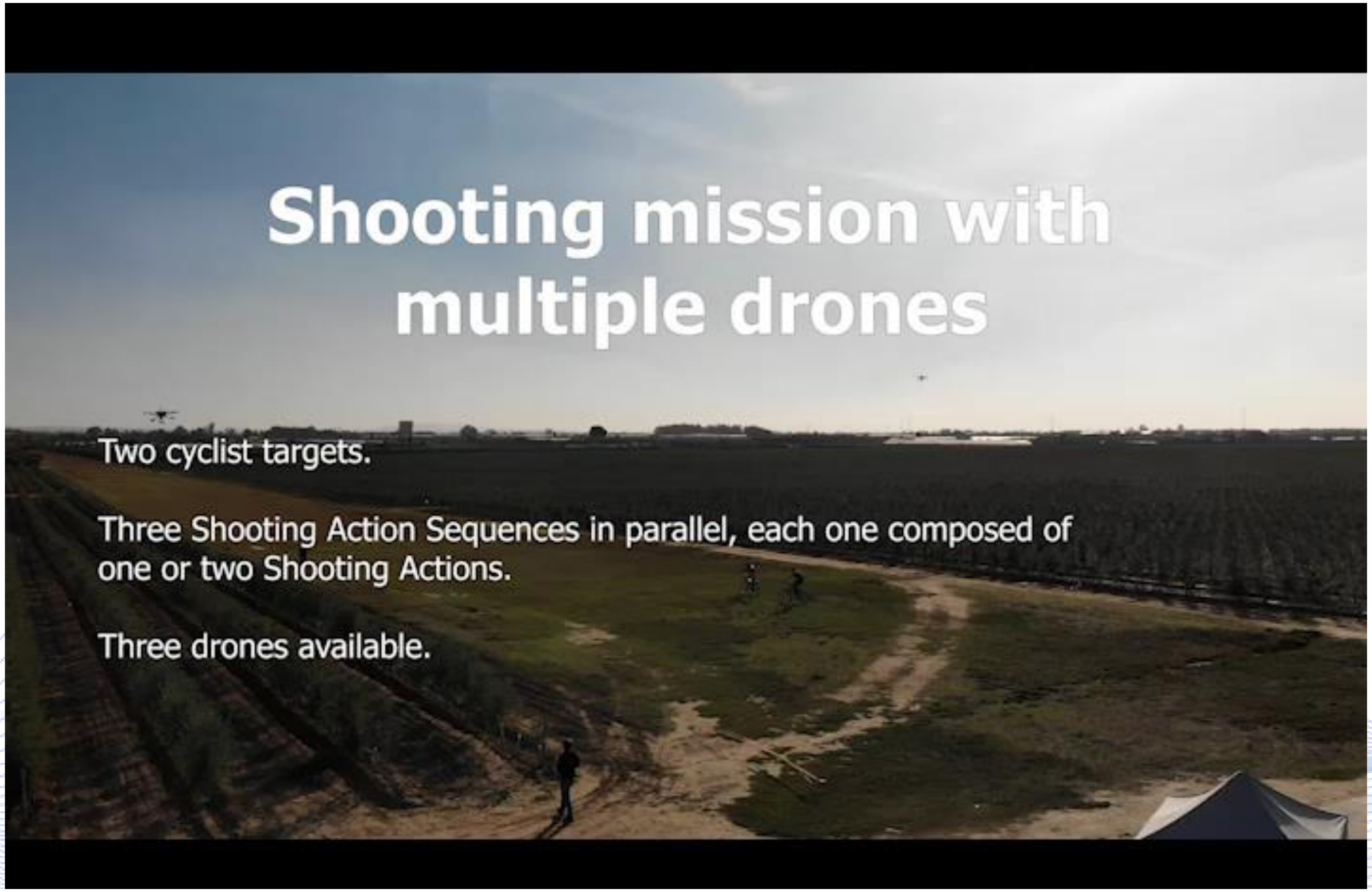
Example

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



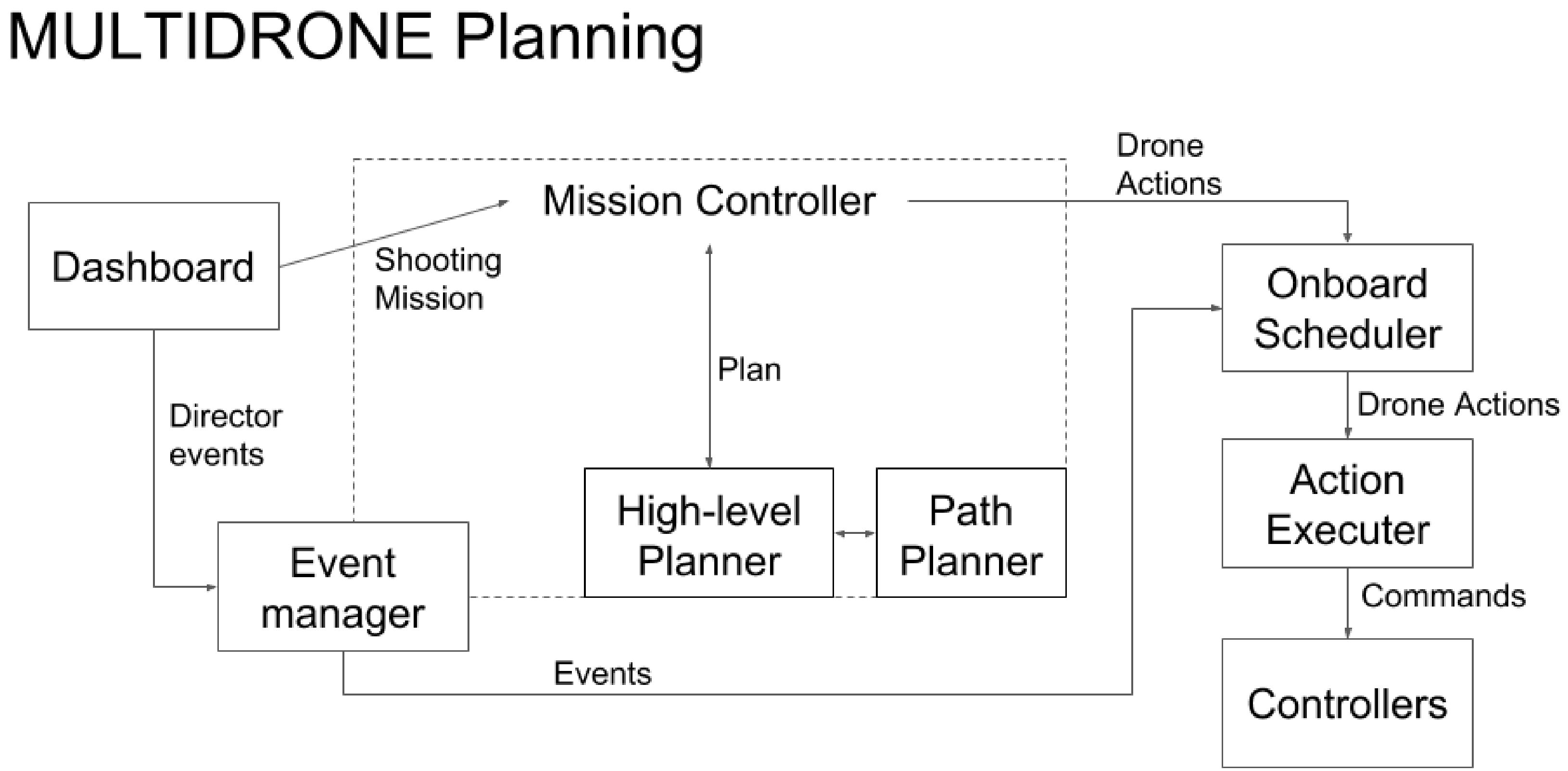


AV Mission example



AV Shooting mission with 3 drones (5 different shootings).

Mission Planning architecture



Mission Planning and Control

Mission Controller:

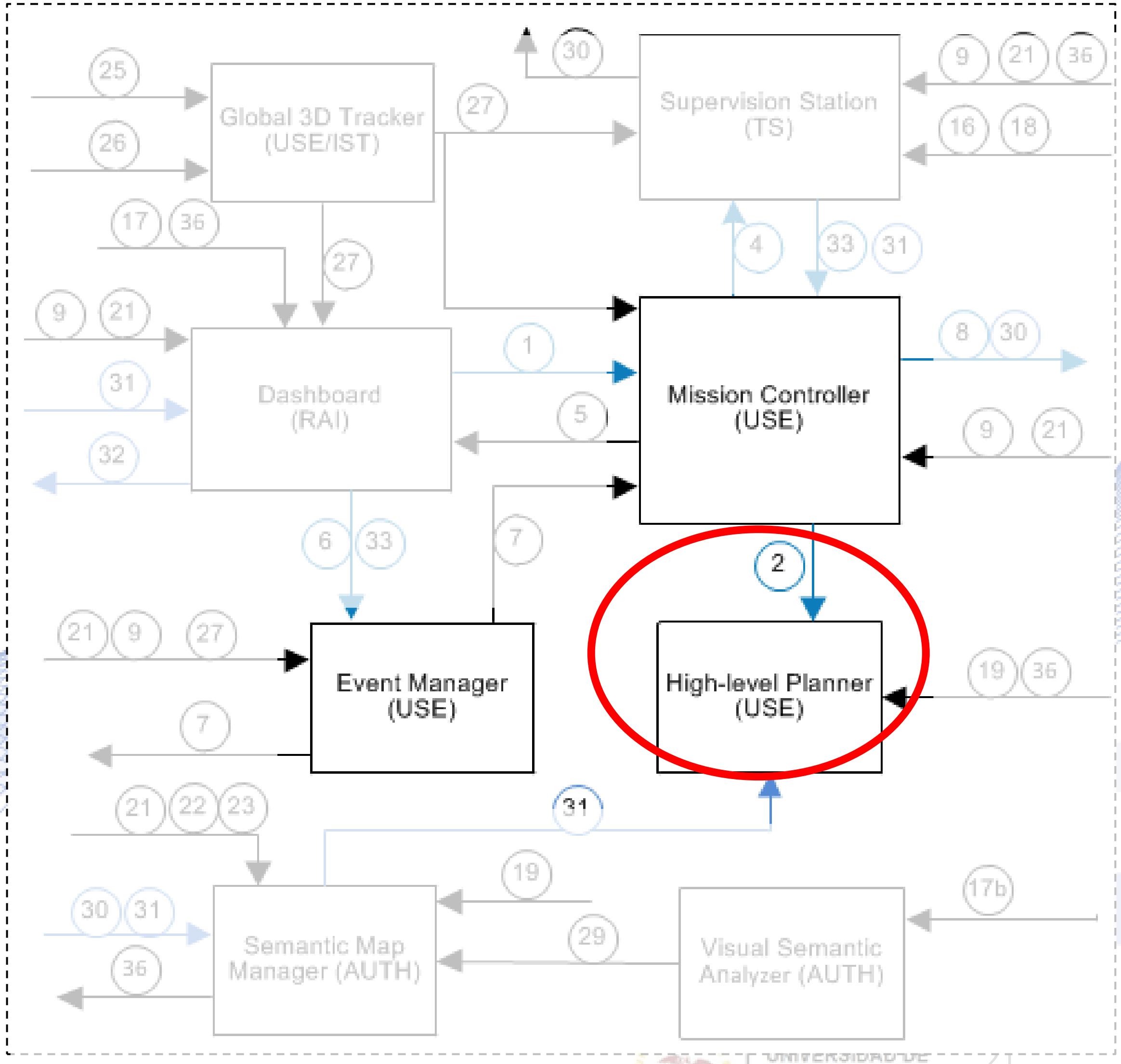
- Requests new plans, safety checks
- Sends ***drone actions*** to each drone.
- Monitors mission execution.

High-Level Planner:

- Computes plans.

Event Manager

- Receives and generates events to trigger drone actions.



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Drone operation/control modes

- ***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.

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).

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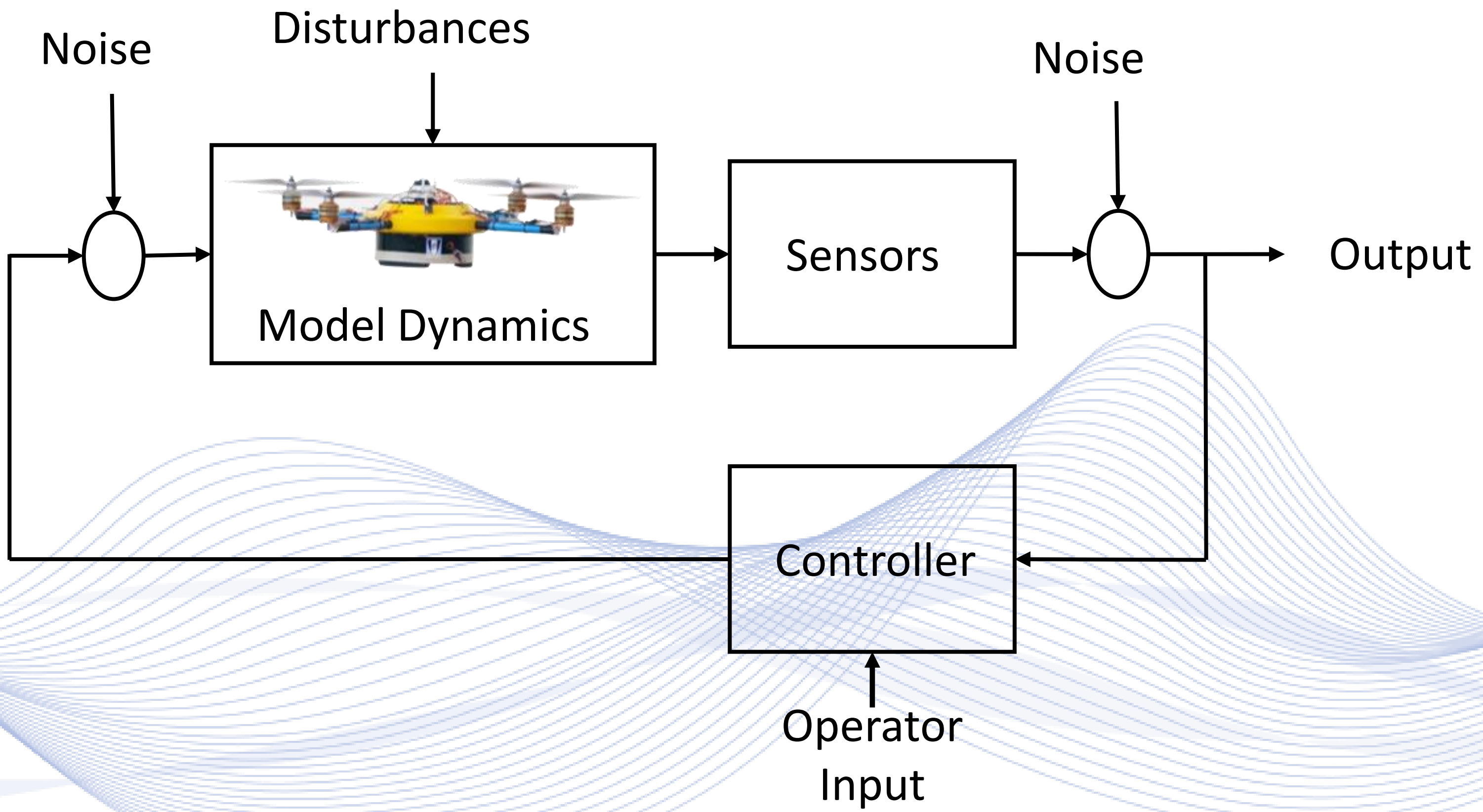
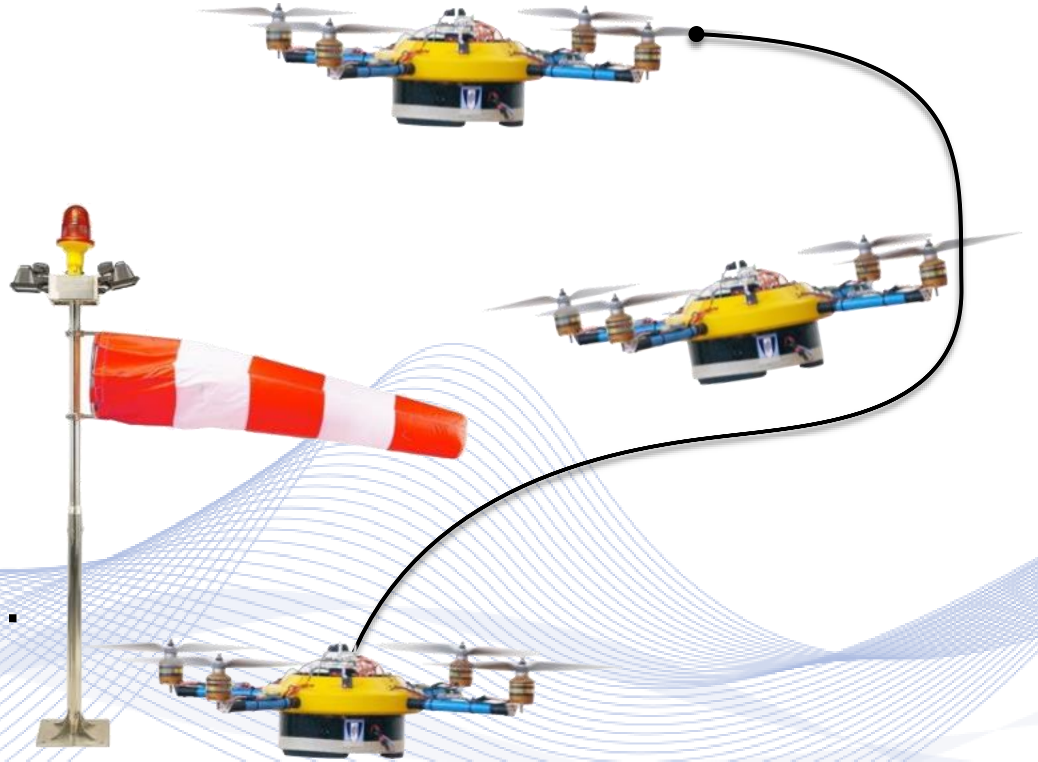
Drone as Control System



Control Objectives – Trajectory Tracking



Track a trajectory.

Realistic model.

Robustness to disturbances.

Bounded actuation.

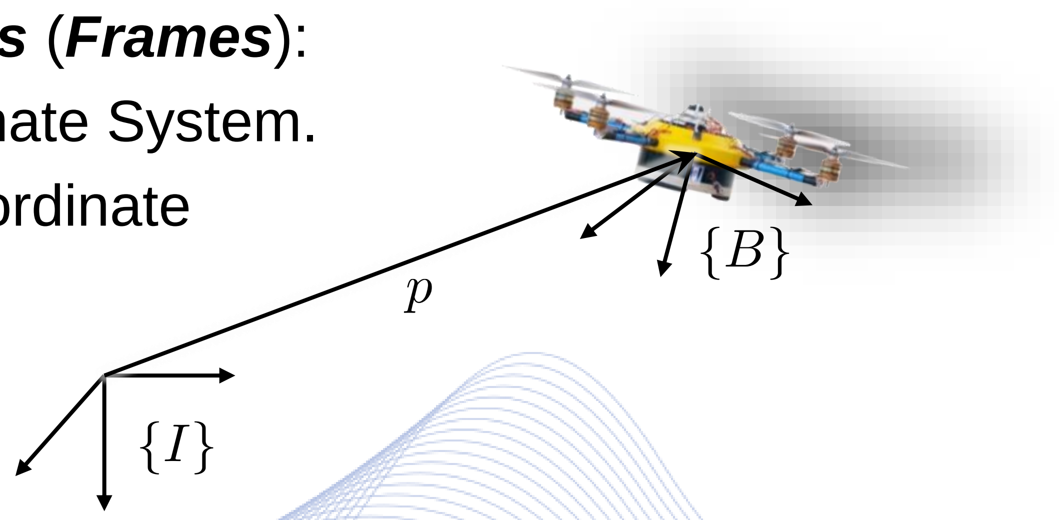
Large basin of attraction.

Rigid-body equations of motion (I)

Reference Coordinate Systems (***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 $\{I\}$

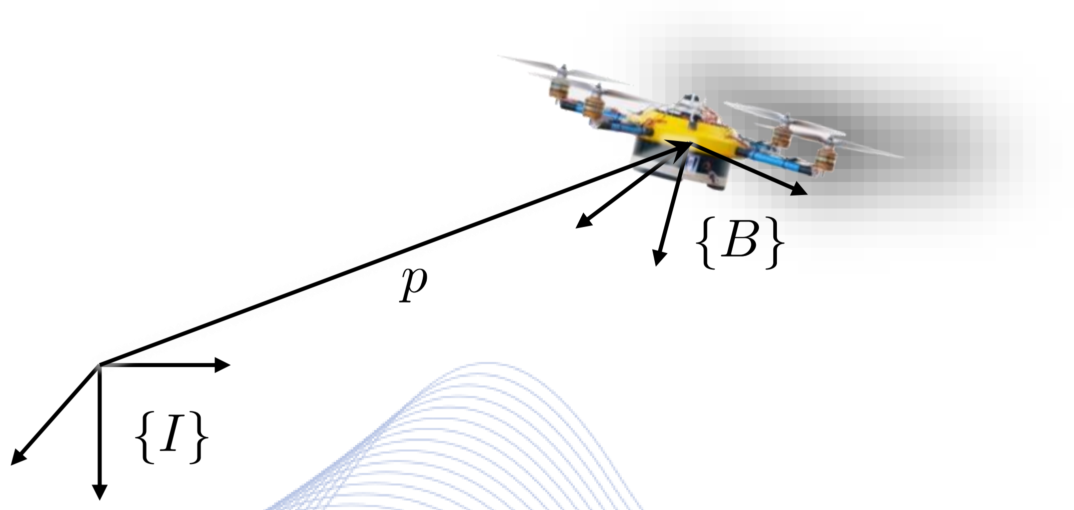
$v \in \mathbb{R}^3$ – Linear velocity of $\{B\}$ relative to $\{I\}$

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

Rigid-body equations of motion (II)

Drone kinematic model:

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



Drone dynamic model:

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

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

$m \in \mathbb{R}$ – mass

$J \in \mathbb{R}^{3\times3}$ – Tensor of inertia expressed in $\{B\}$

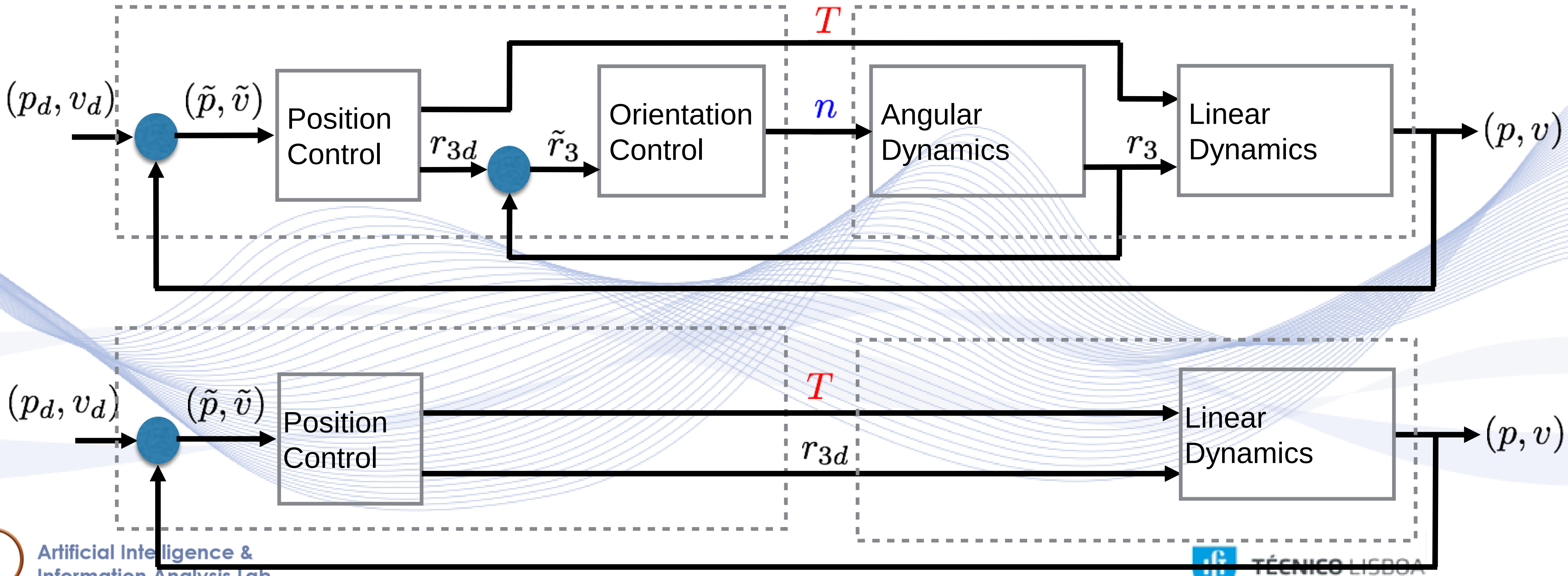
$f \in \mathbb{R}^3$ – External forces expressed in $\{I\}$

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

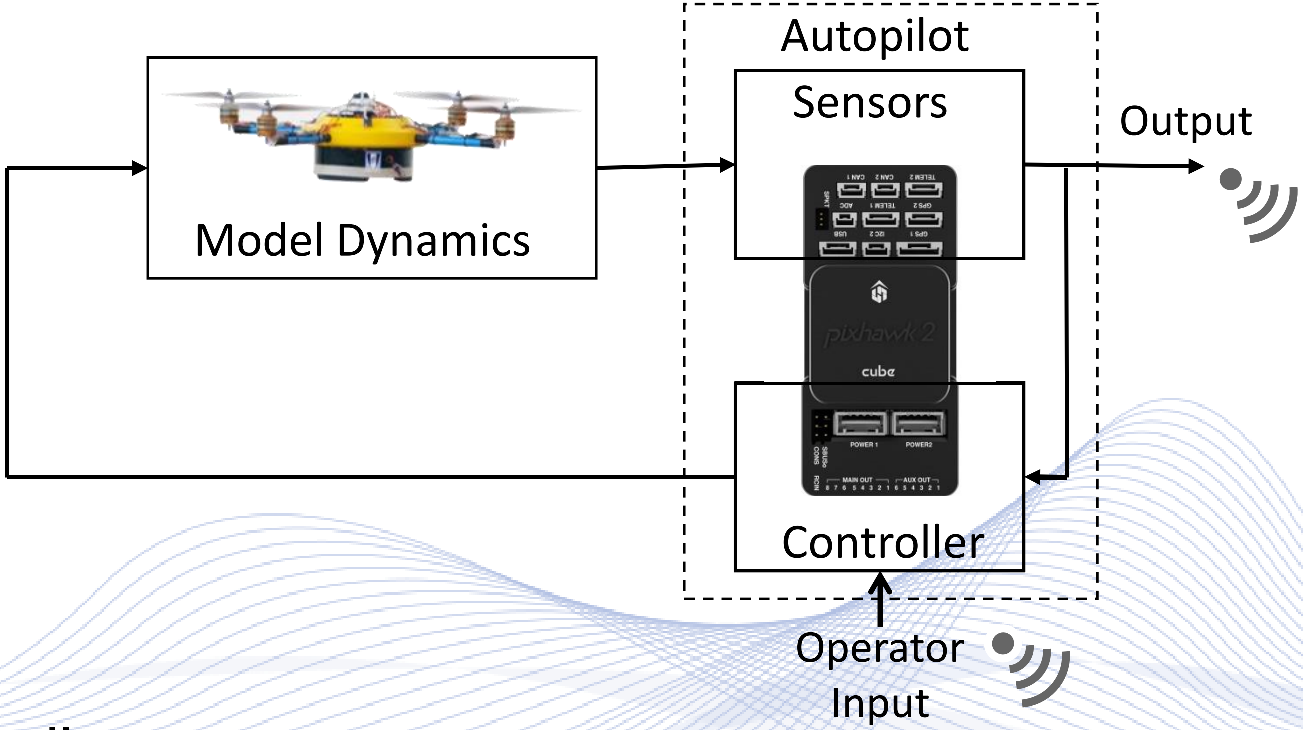
Hierarchical Control

It explores time-scale separation:

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

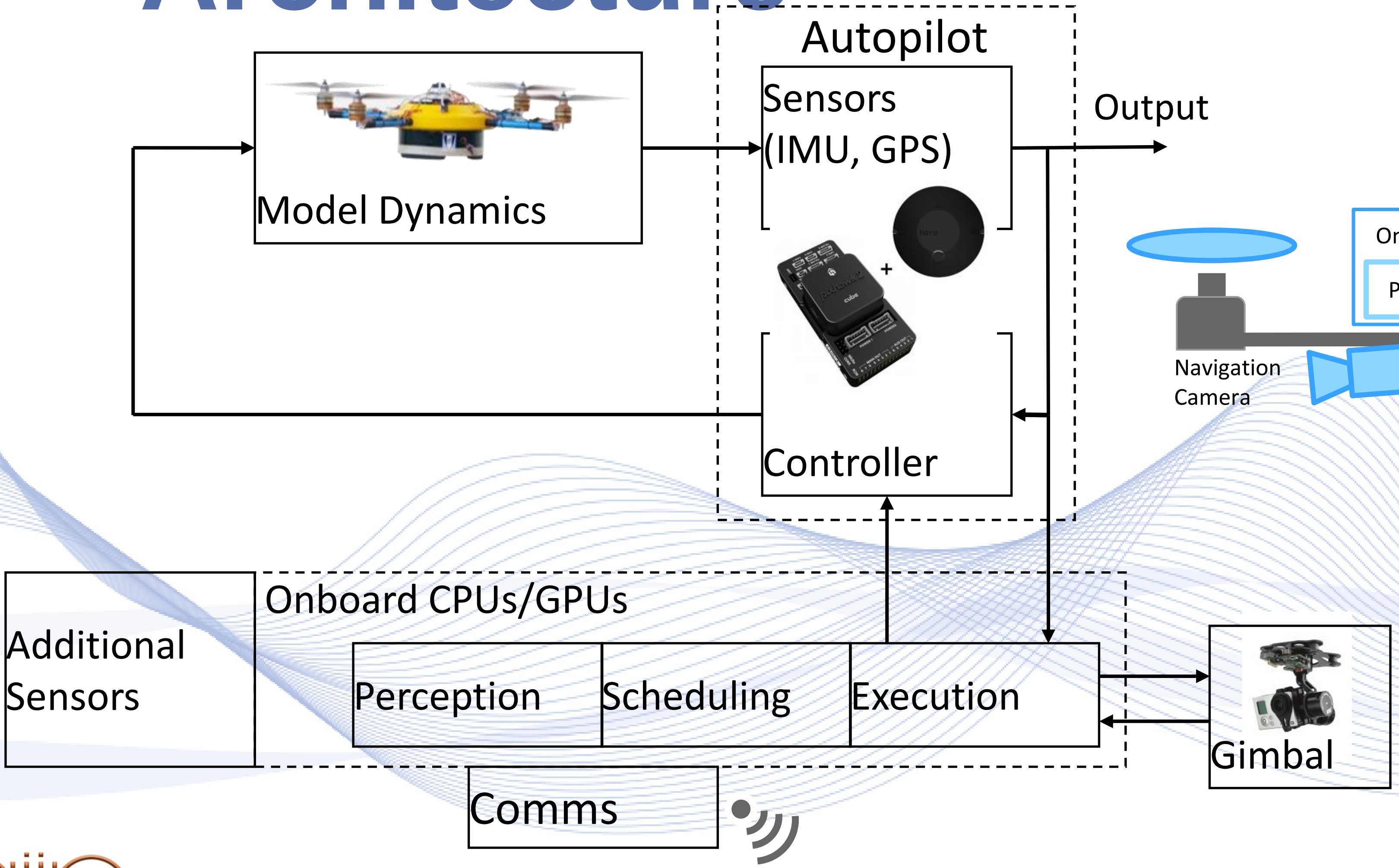


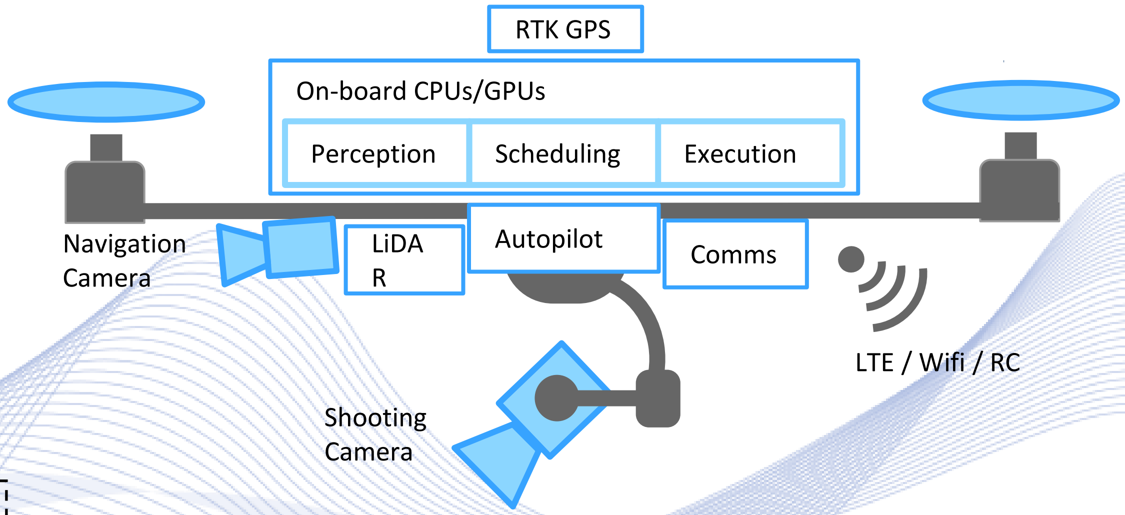
Autopilot



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

Multiple-drone Onboard Architecture





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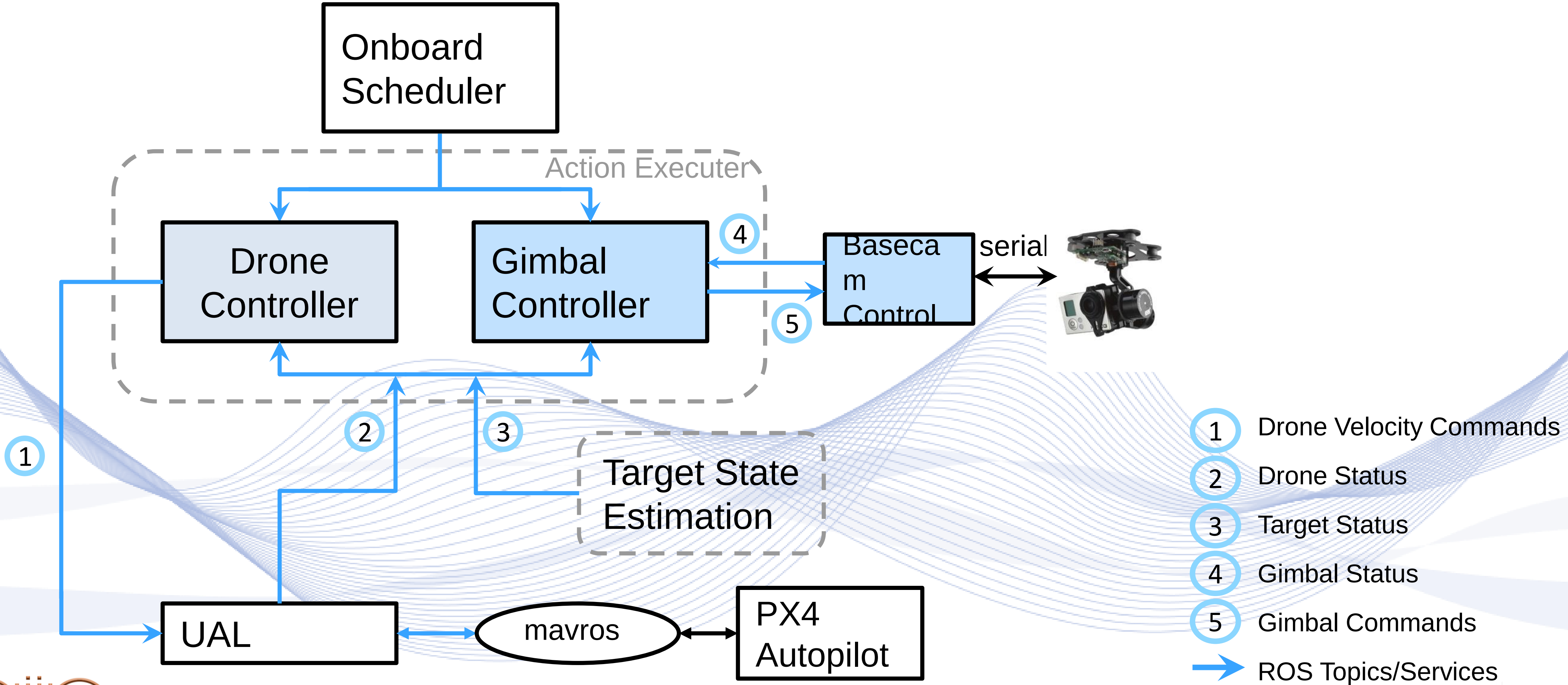
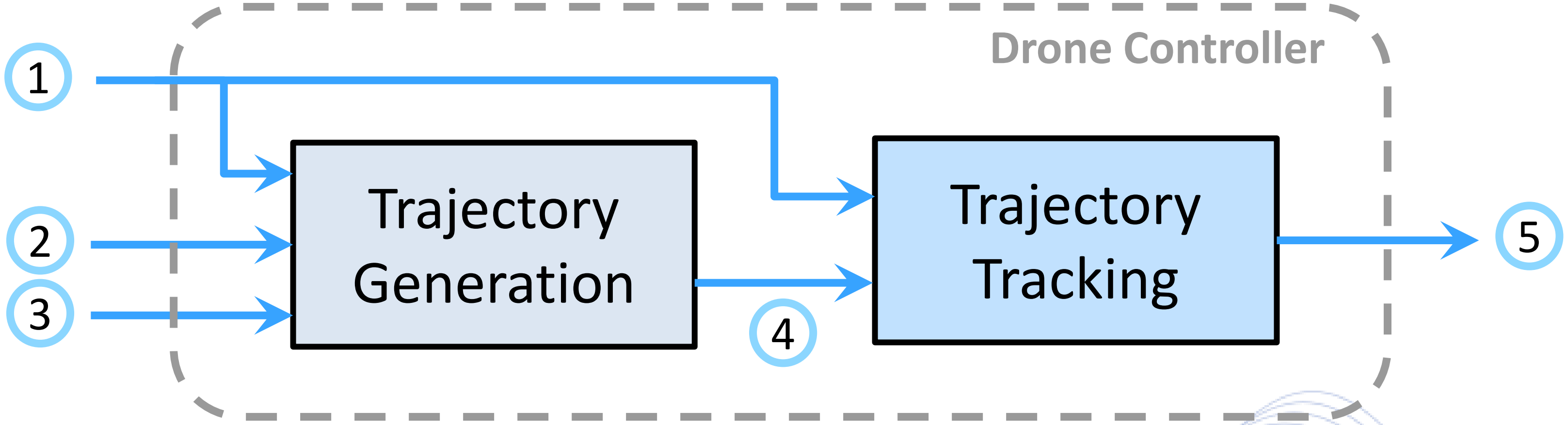
Action Execution

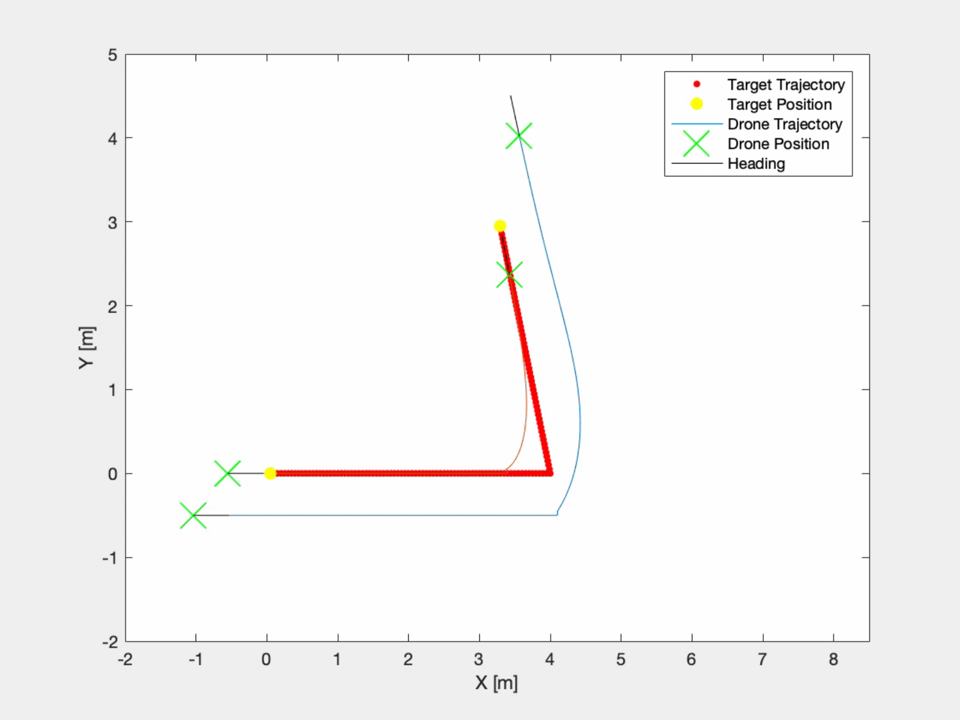


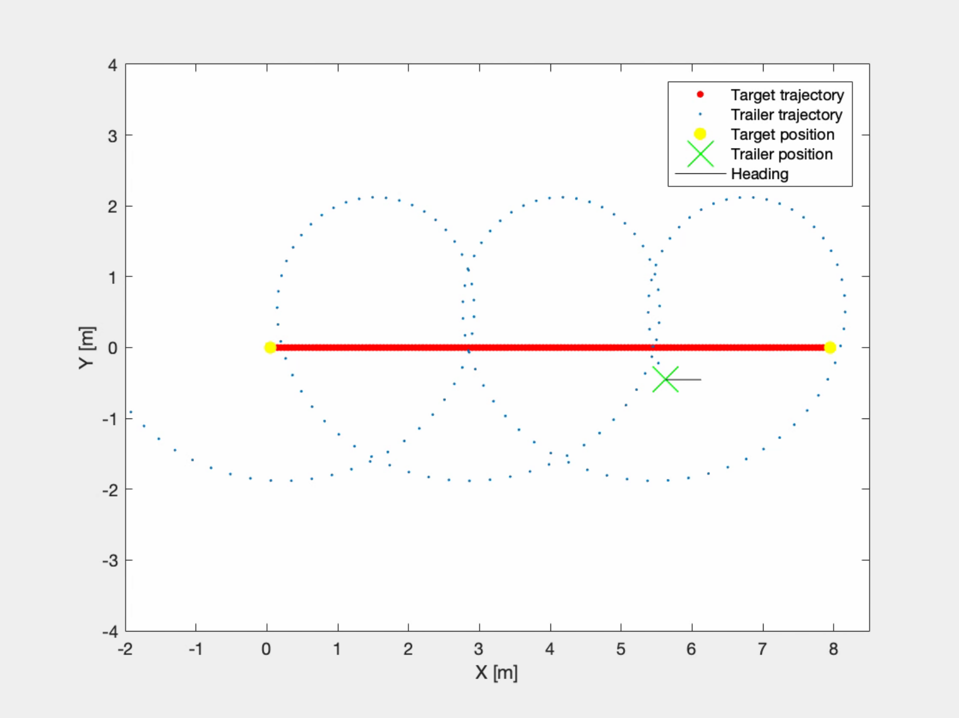
Drone Controller



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

Drone Control for shot execution





CHASE

$$r_0 = \dot{r} = 0$$

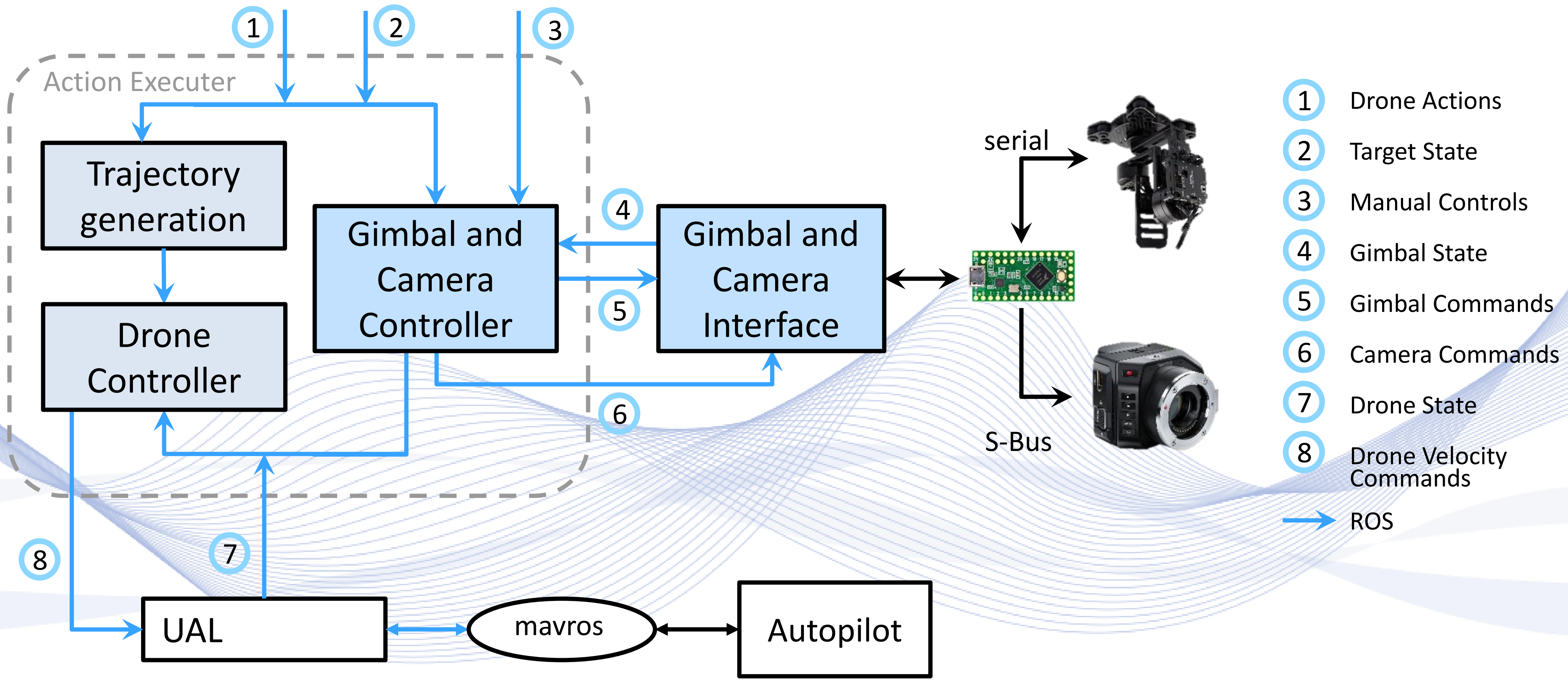
FLYBY

$$r_0 = \begin{bmatrix} -1 \\ -1 \end{bmatrix}, \dot{r} = \begin{bmatrix} 0.8 \\ 0 \end{bmatrix}$$

ORBIT

$$r_0 = 2\begin{bmatrix} \cos(\pi) \\ \sin(\pi) \end{bmatrix}, \dot{r} = 2\begin{bmatrix} -4\sin(\pi + 4t) \\ 4\cos(\pi + 4t) \end{bmatrix}$$

Action Executer



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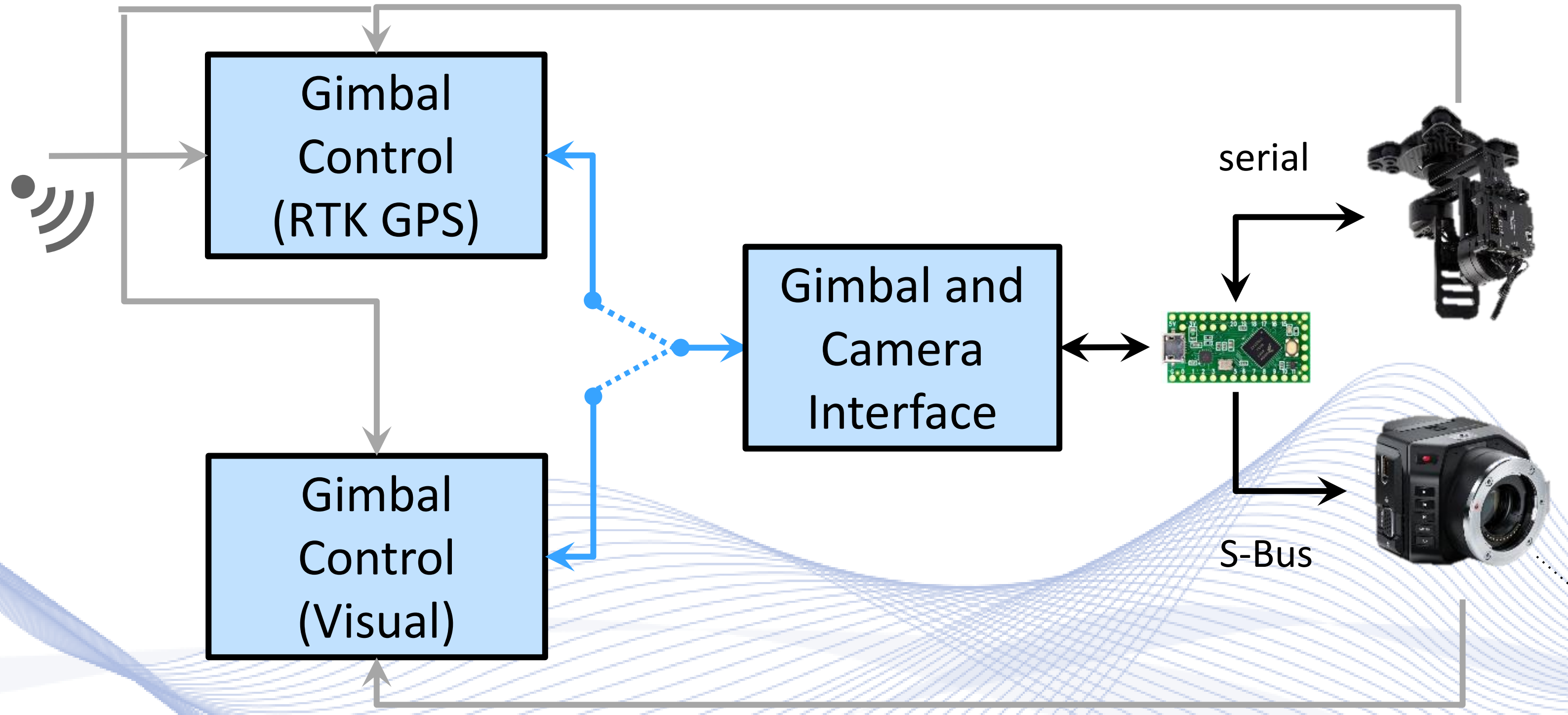
Gimbal Control



Gimbal control:

- Point at target (with/without offset).

Camera control:

- Remote focus and zoom commands.

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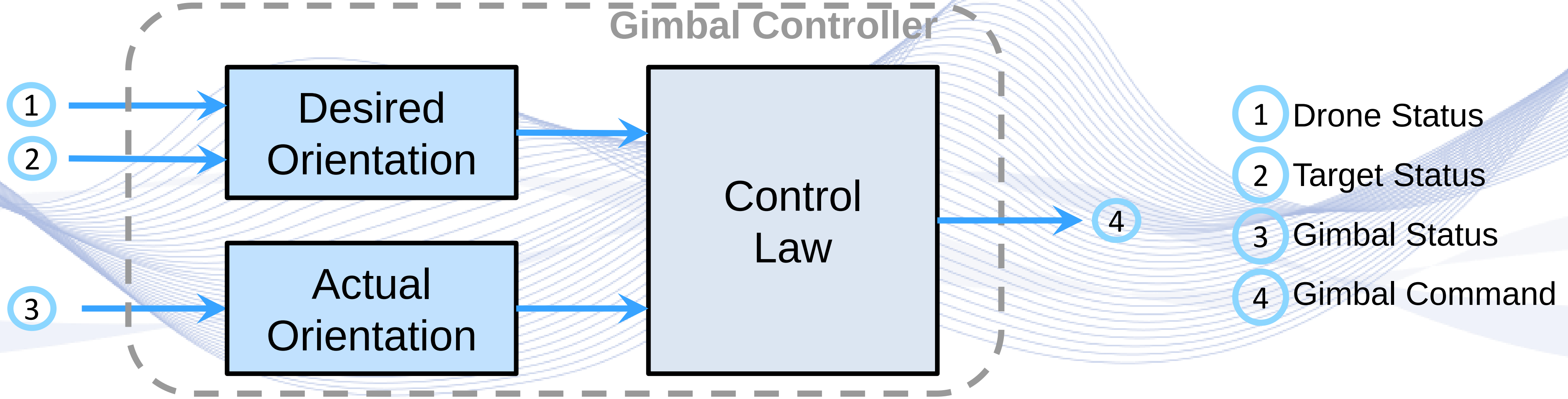
Gimbal control

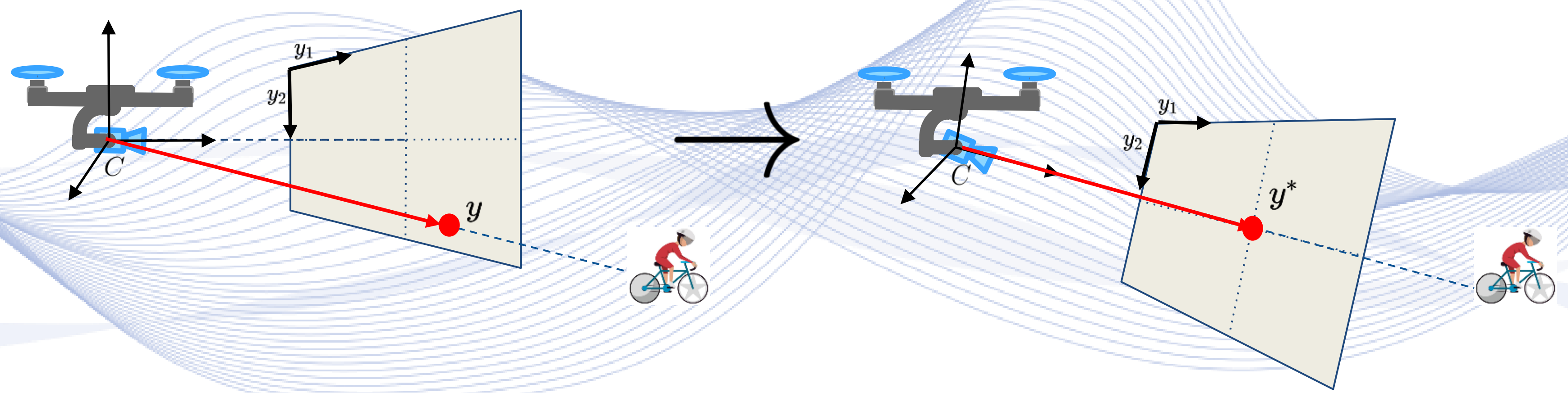
- Gimbal control objective: ***Point towards the target.***
- Approach: Treat gimbal control independently from drone control.



Vision-based Gimbal Control

- From image error to attitude error:

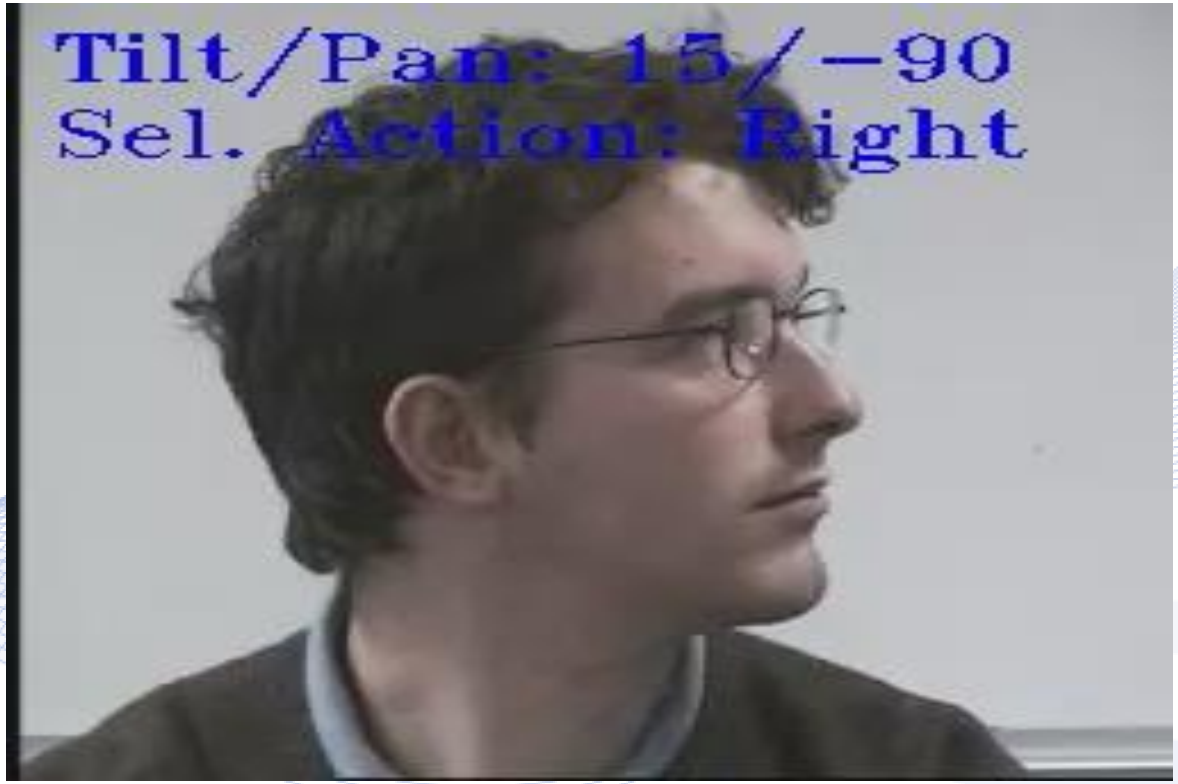
$$\begin{bmatrix} y \\ 1 \end{bmatrix} \rightarrow \begin{bmatrix} y^* \\ 1 \end{bmatrix} = A \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \Leftrightarrow q \rightarrow \begin{bmatrix} 0 \\ 0 \\ \|q\| \end{bmatrix}$$



Vision-based Gimbal Control

GPS-based Gimbal Control

Drone control using Deep Reinforcement Learning



Deep RL Drone Control to take frontal person shots [PAS2018a].

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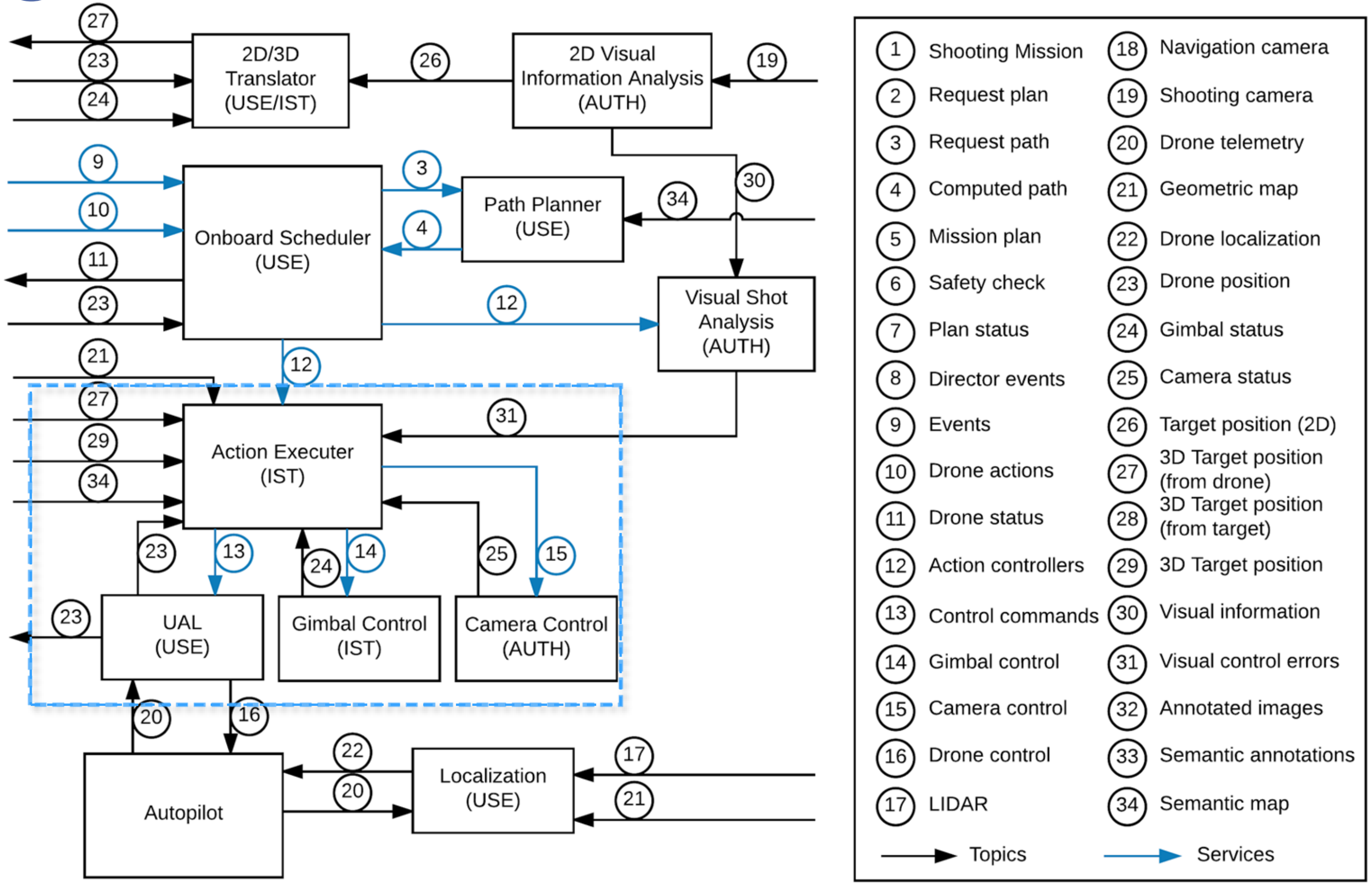
Onboard functional architecture

Onboard CPUs/GPUs

Perception	Scheduling	Execution



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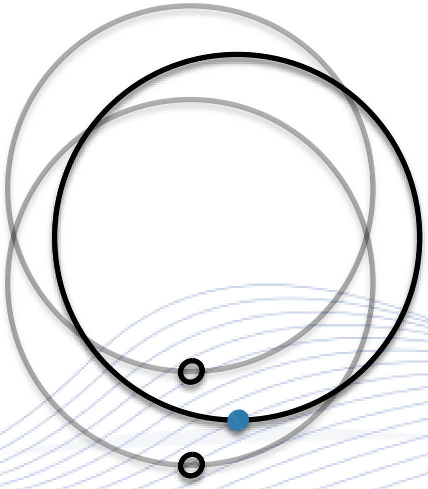
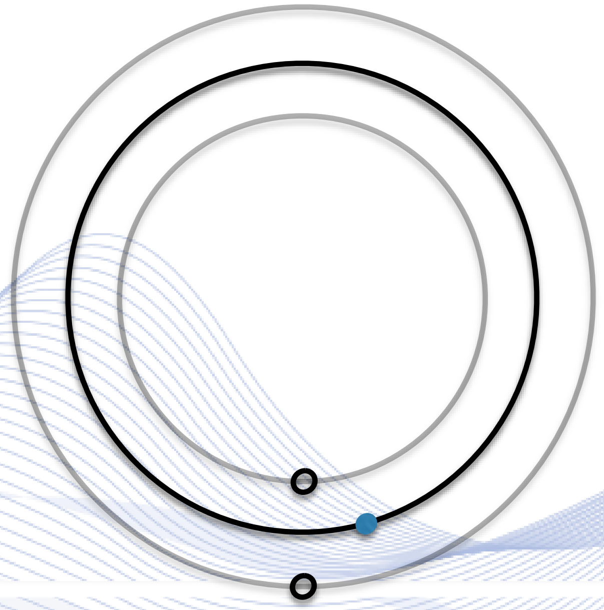
Leader-following for formation control

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





In inertial frame:
Translated identical paths

In trailer frame:
Different paths, no superposition

Drone Control for shot execution

- Trajectory generation – Trailer approach

$$p_D = p_T - {}^I_D R(d - r)$$

$$r = r_0 + \dot{r}t$$

Virtual trailer link

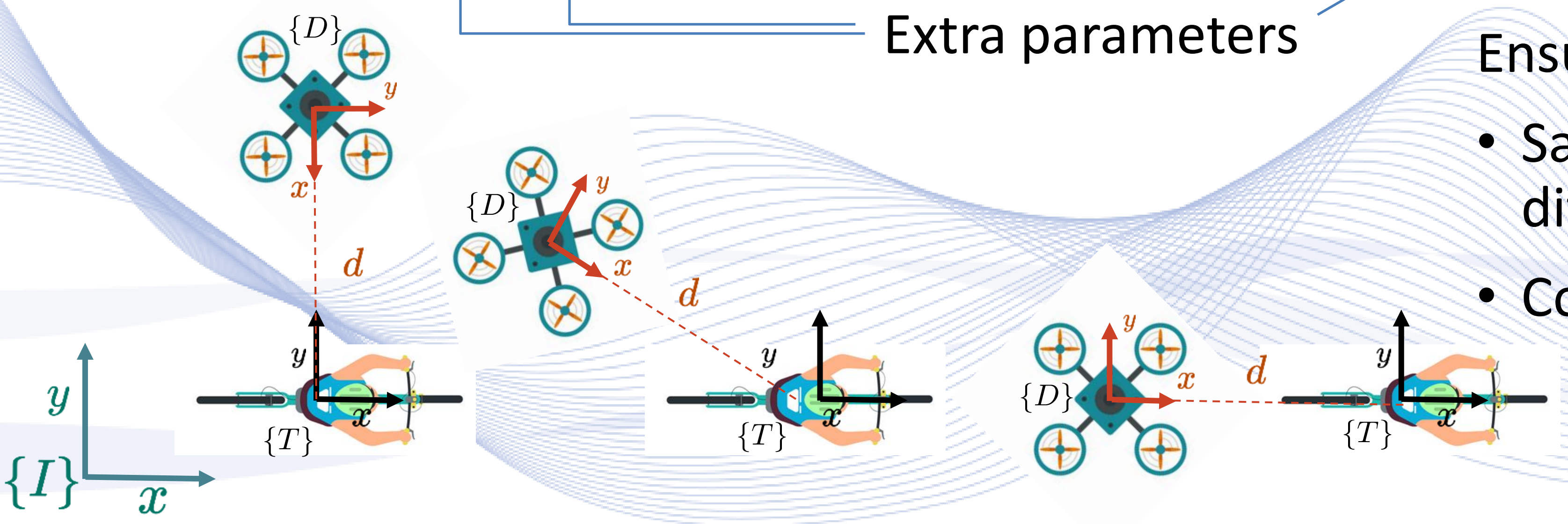
Extra parameters

Adequate for

- Smooth target tracking
- Execution of different shot types

Ensures

- Same asymptotic behavior, different initial conditions
- Convergence of the formation

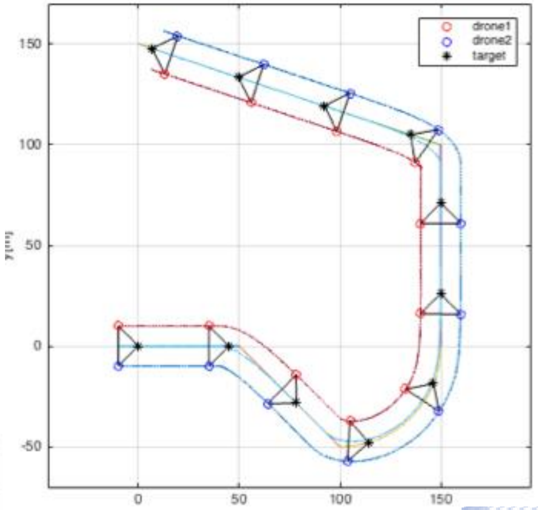


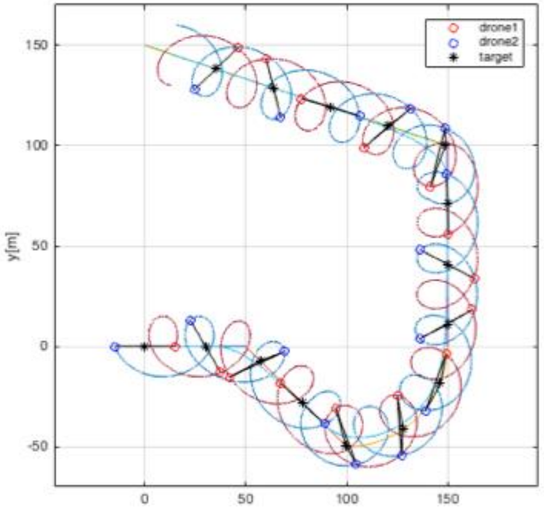
[TCST2019, Automatica2017]

Drone Formation Control

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

- Examples:
  SA1 – constant relative positions
  SA2 – Orbit trajectory





PARKOUR MISSION

Drone 1

1) Still shooting action
2) Lateral shooting action
3) Orbit shooting action

Drone 2:

1) Fly through shooting action
2) Flyby shooting action

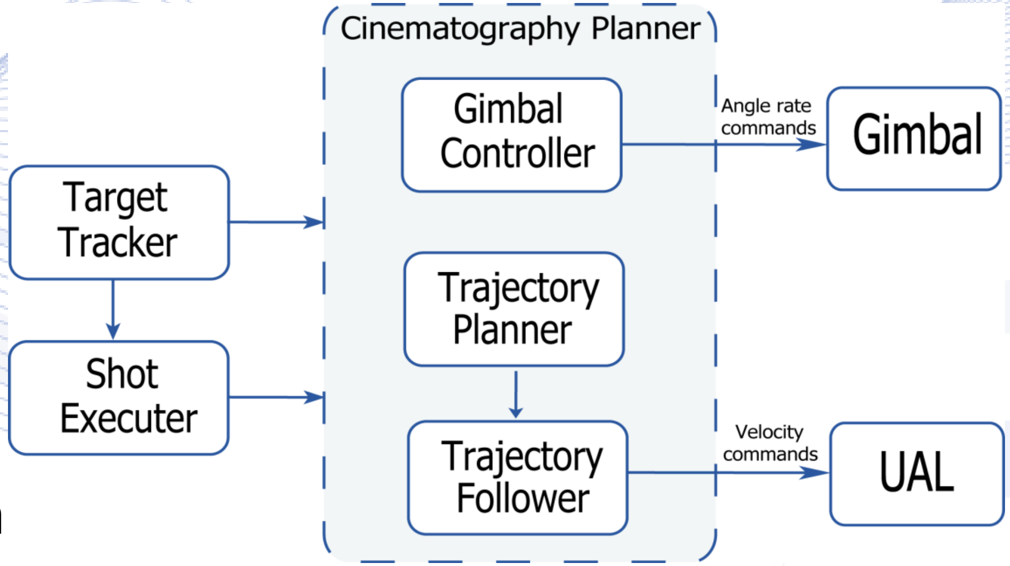
MultiDrone

Optimal trajectory planning for aerial cinematography

- Team of drones filming a target
- Drone trajectory planning for filming

[ECMR2019, ACA2019]

- ***Non-linear constrained Optimization Problem***:
  - Objective: visually pleasant trajectory
  - Constraints: dynamics, collision avoidance, cinematography constraints
- To deal with complexity:
  - Camera is pointing at target (gimbal control)
  - Receding horizon planner for drone trajectory on



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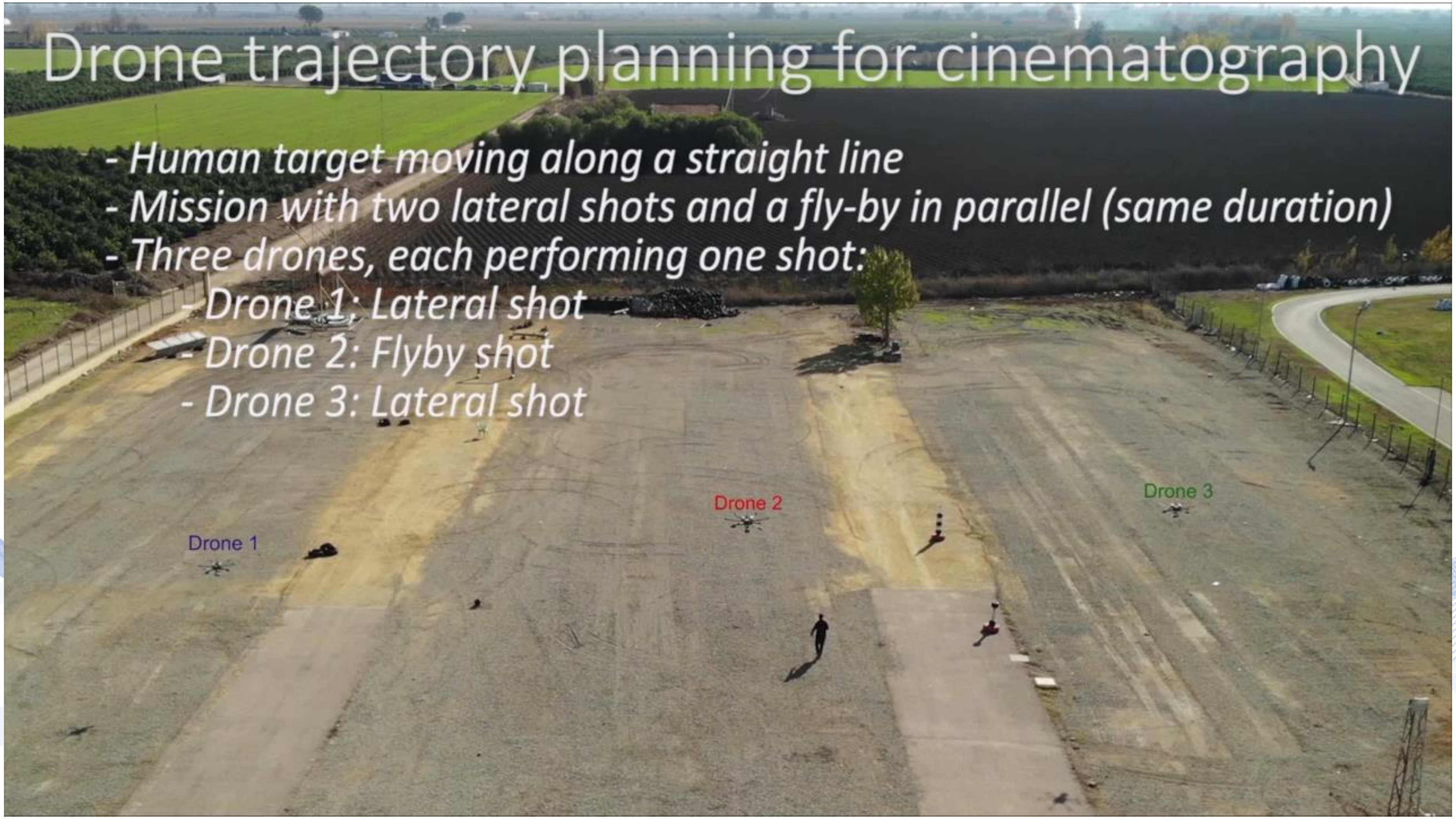
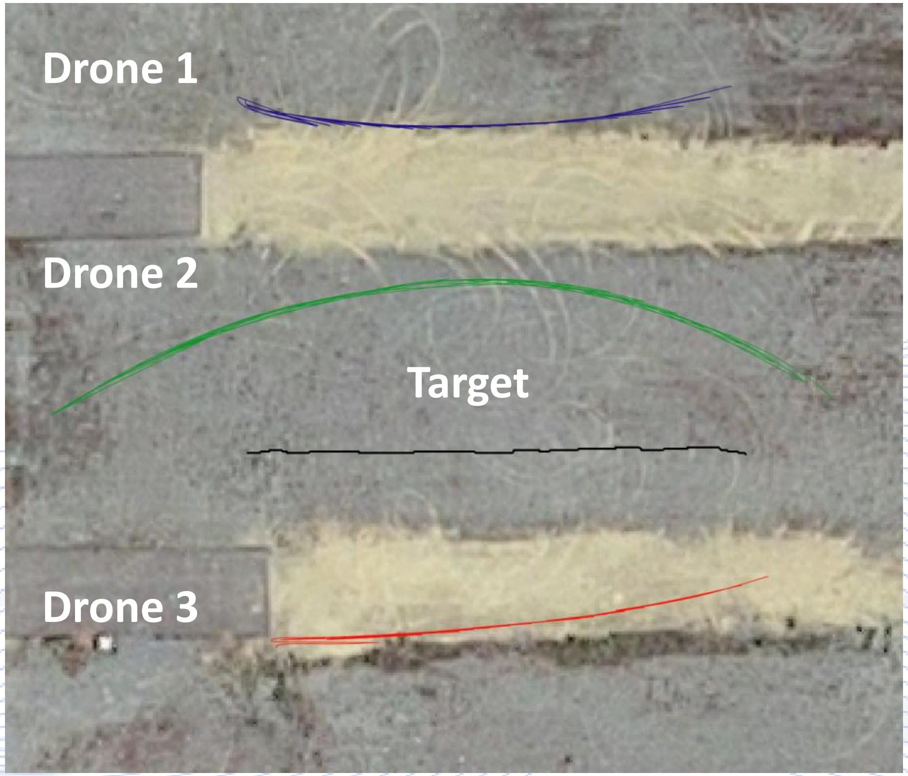
Multi-drone trajectory planning



Multi-drone trajectory planning



Optimal trajectory planning.

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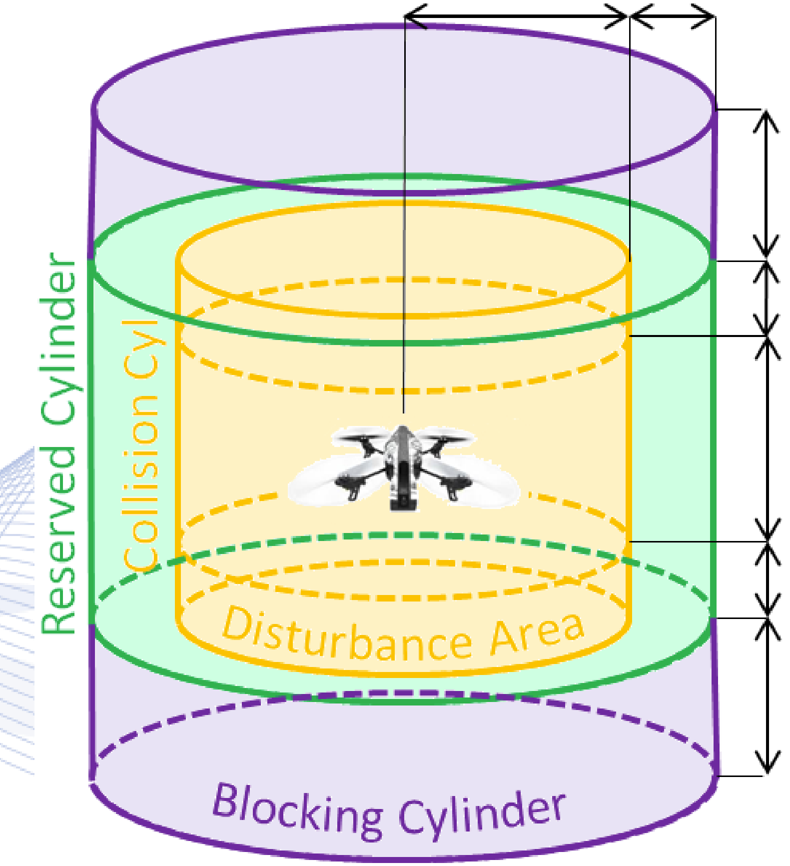
Collision avoidance with multiple drones

- Objective:
  - Avoid collisions during navigation with other drones and obstacles.
- Assumptions:
  - LIDAR sensors on board to detect obstacles.
  - Communication system to share drone positions in the swarm.
- Constraints:
  - Low computational resources.
  - Inaccurate positioning system.

Collision avoidance with multiple drones

Drone collision issues:

- 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.

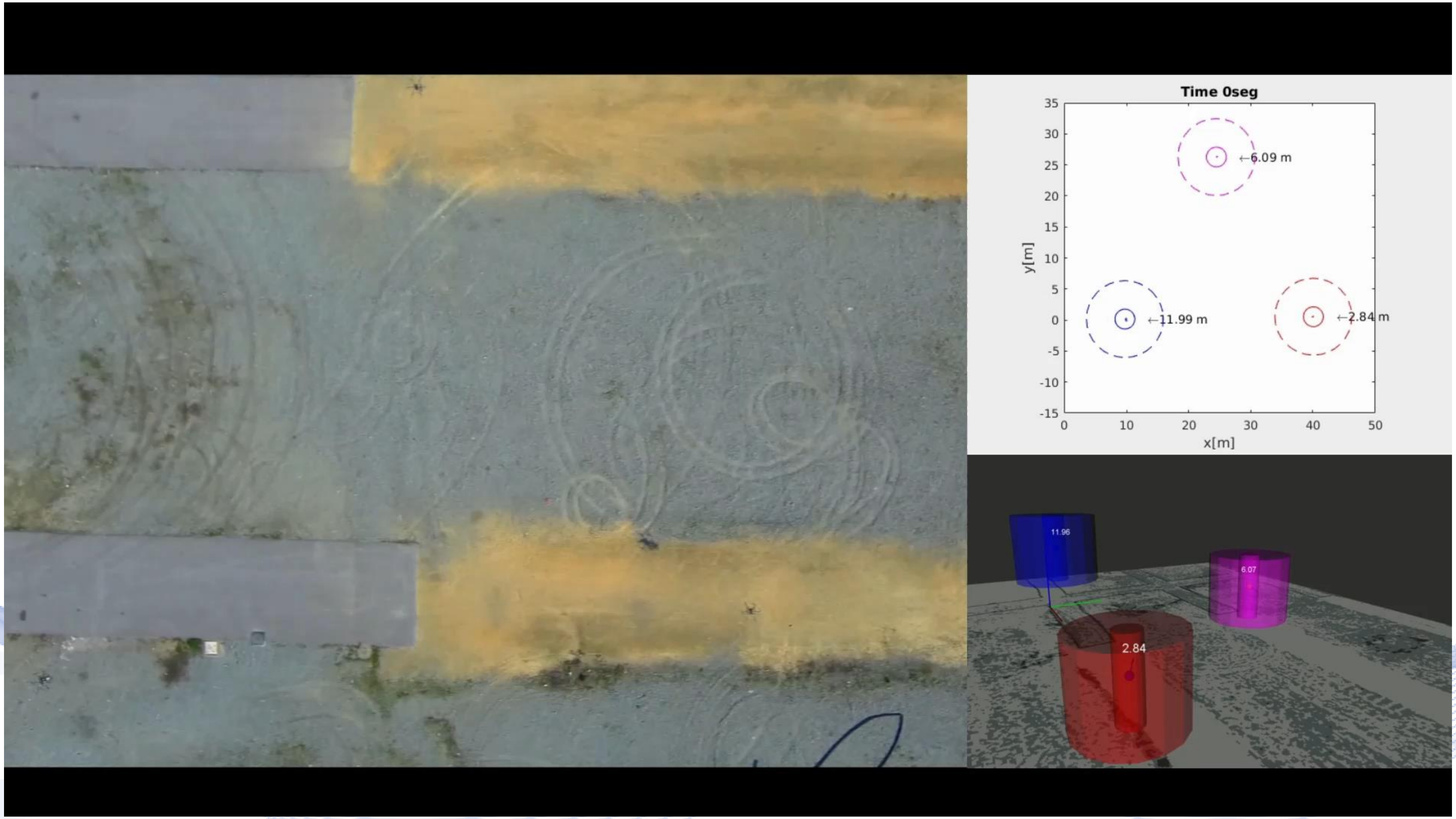


Collision avoidance experiments

Outdoors collision avoidance evaluation with three drones.

- Communicated drone positions based on noisy GPS (2 m).
- Different sizes for collision cylinders depending on wind.
- Tests with incremental complexity and risk.

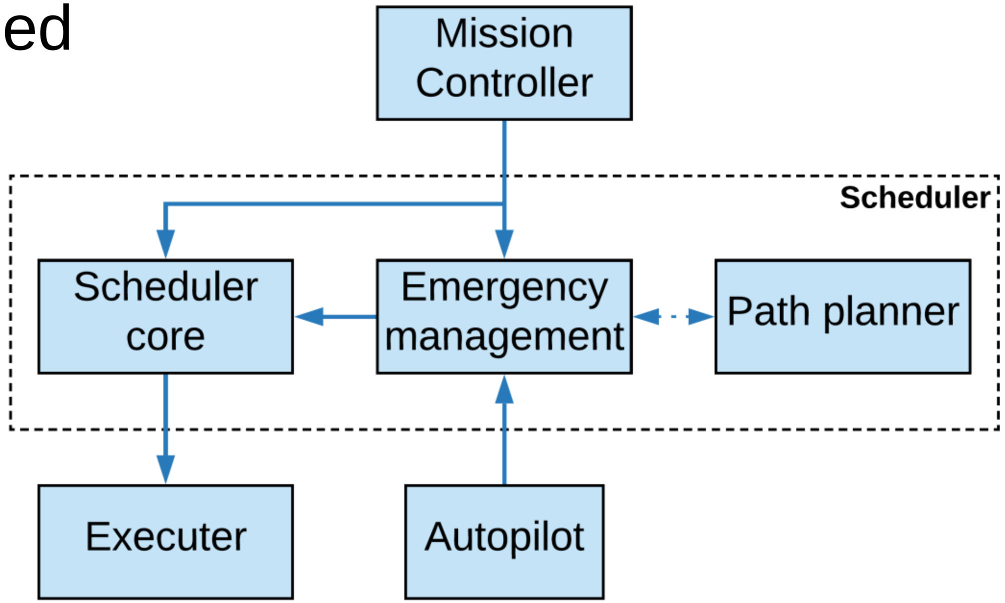
Collision avoidance experiments



Outdoors collision avoidance evaluation with three drones.

Drone emergency management

- Distributed onboard scheduler to synchronize shots using an event-based mechanism.
- Three components:
  - Scheduler core,
  - Emergency management,
  - Path planner.
- Safety in two levels:
  - Collision avoidance in the Executer
  - Emergency management to handle high level alarms.



[EUSIPCO2019]

Multiple Drone Mission Planning and Control

- Multiple drone mission planning.
  - Audiovisual shooting mission definition.
  - Mission Planning Vocabulary.
  - High-level planning.
  - Path planning.
- Manual drone operation/control.
- **Automatic drone mission control.**
  - Single drone flight control.
  - Gimbal and camera control.
  - Multiple drone control architecture.
  - Drone formation control.
  - Collision avoidance.
- **Vision-based single drone control.**

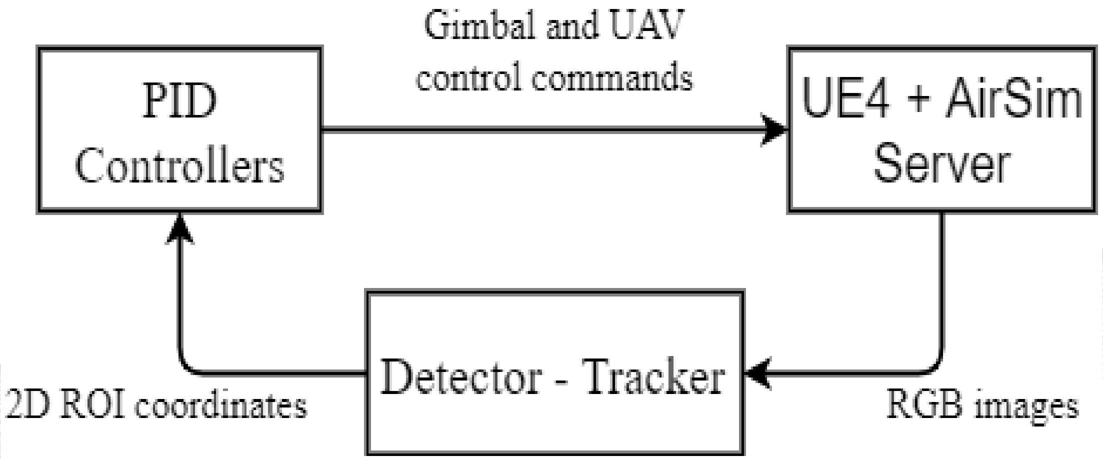
Vision-based drone control

- A set of purely vision-based drone controllers can be designed for autonomous UAV cinematography, separately for each target-tracking CMT.
- ***They require neither drone nor target 3D state knowledge*** (e.g., for GPS-denied time intervals or environments).
- The only requirement is for the target to initially be visible on the video frame.
- Several UAV/camera motion types can be defined as a set of requirements that interrelate 2D visual information, drone trajectory and camera orientation.

Vision-based drone control

The overall architecture consists of:

- An environment along with the AirSim server.
- A 2D visual detector/tracker [ICIP2018] [RCAR2019] [CVPR2017] [CVPR20178].
- The designed PID controllers.
- Multiple AirSim clients for extracting and sending back information to the server
- ROS back-end for interprocess communication (excluding the RPC-based server-clients interaction).



Conclusions

Multiple drone mission planning and control:

- Support the activity of the director (easier video production).
- Real-time planner implementation.
- Multiple-drone cinematography.
- Drone trajectory and formation control for ***aerial visual shot execution***.
- Optimal trajectory planning for **aerial cinematography**.
- Drone gimbal and camera control.
- Visual drone and gimbal/camera control.

Q & A

Thank you very much for your attention!

More material/lectures in
http://icarus.csd.auth.gr/cvml-web-lecture-series/

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