Introduction to Autonomous Systems

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Artificial Intelligence & Information Analysis Lab

Autonomous Systems

- **Definitions**
- Applications
- Technologies
  - Mission Planning
  - Mission Control Perception
  - Intelligence
  - Embedded computing
  - Autonomous systems swarms
  - Communications

Autonomous System definitions

Autonomous system etymology:

- Greek words ‘***αυτο***’ (auto, own) and ‘***νόμος***’ (law, rule)
- A system that operates using own rules/laws
- A system that operates independently:
  - without reference to other entities
  - without reporting to any authority.

Autonomous System definitions

A fully autonomous system can:

- Gain information about the environment.
- Work for an ***extended period without human intervention***.
- Move either all or part of itself throughout its operating environment without human assistance.
- Avoid situations that are harmful to people, property, or itself unless those are part of its design specifications.

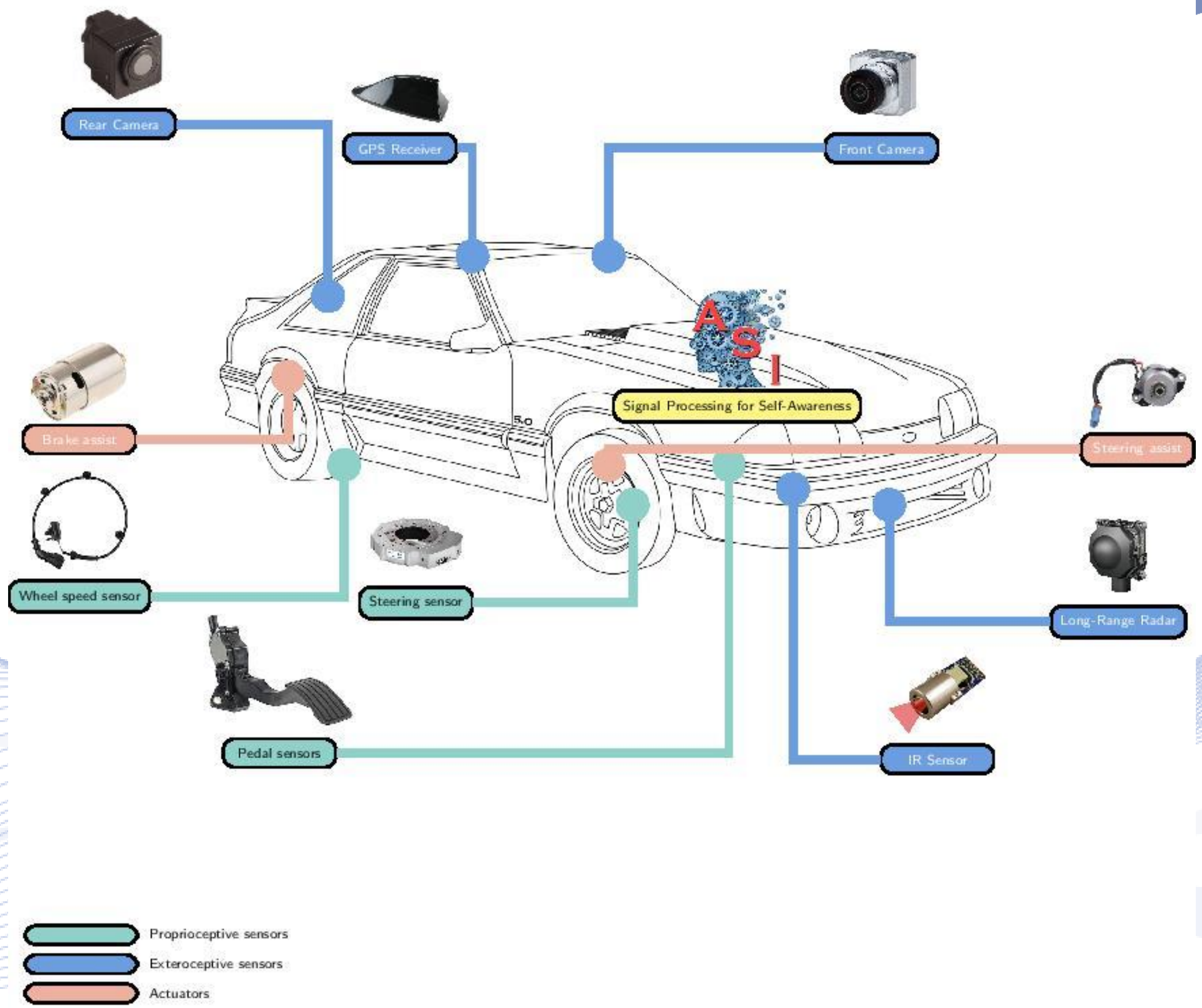
Autonomous System definitions

Sensorial signals (video, acoustic, tactile, radio signals) should be processed by an AS in real time to:

- ***interpret the external situation*** in which it operates;
- relate such a situation to its ***internal state***, by observing it with other proprioceptive sensors, so that it becomes self-aware;
- to use representations to help its own control blocks to ***drive its actuators***;
- ***to be able to explain*** at sub-symbolic and symbolic level the reasons of its own choices.

Autonomous System definitions

Autonomous car structure



Courtecy L. Marcenaro, C. Regazzoni

Autonomous Systems

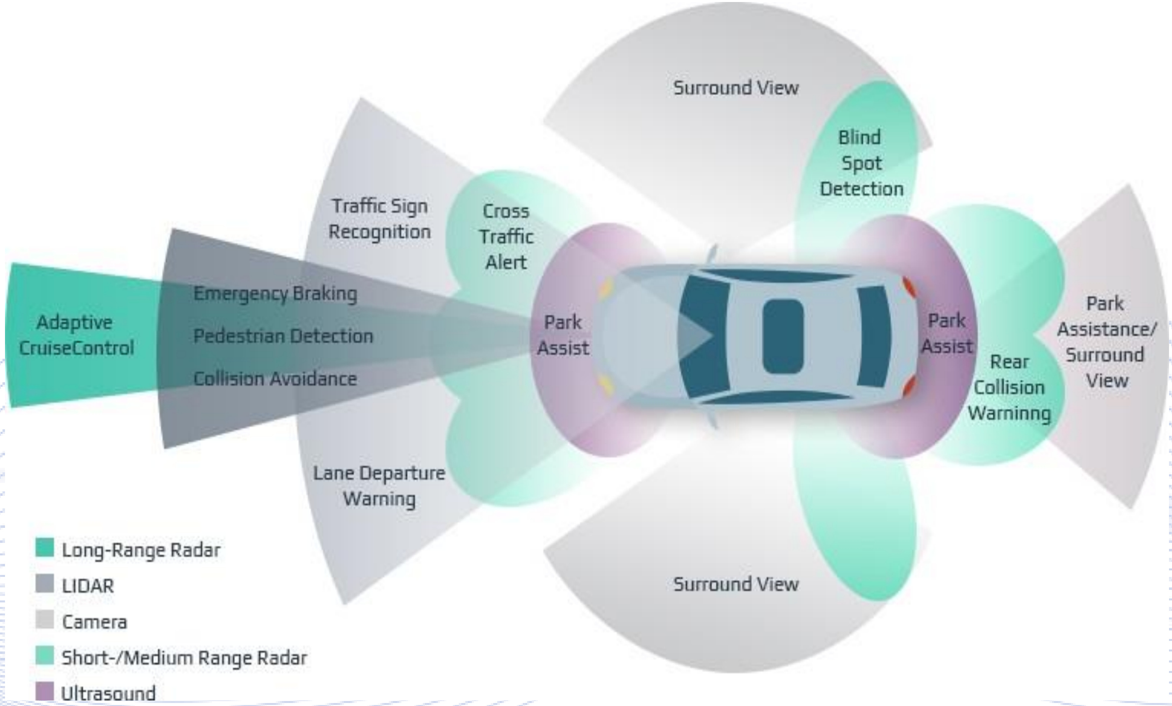
- Definitions
- **Applications**
  - **Cars**
  - **Drones**
  - **Marine systems**
  - **Robots**
- Technologies

Autonomous system applications

- Autonomous cars

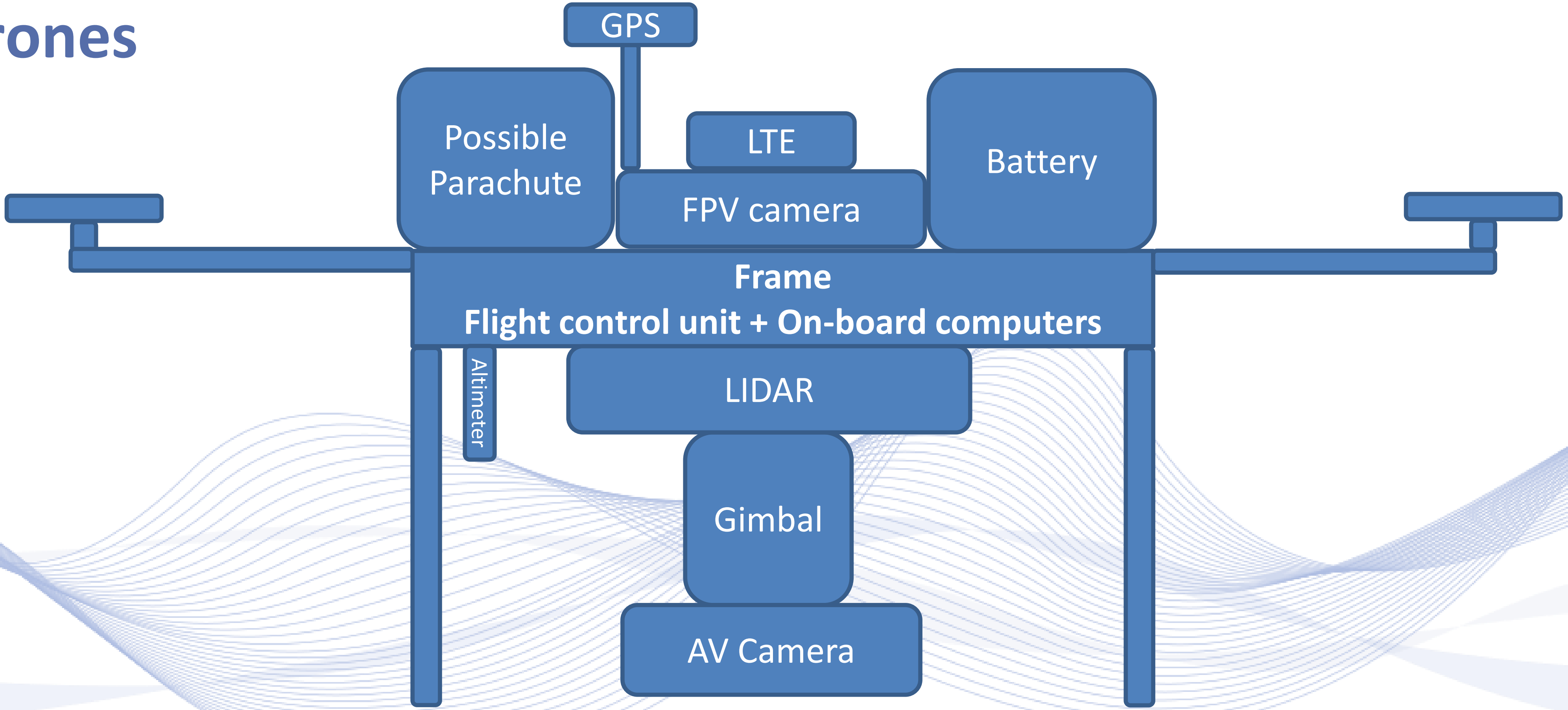
Autonomous system applications

- **Autonomous car sensors and perception**

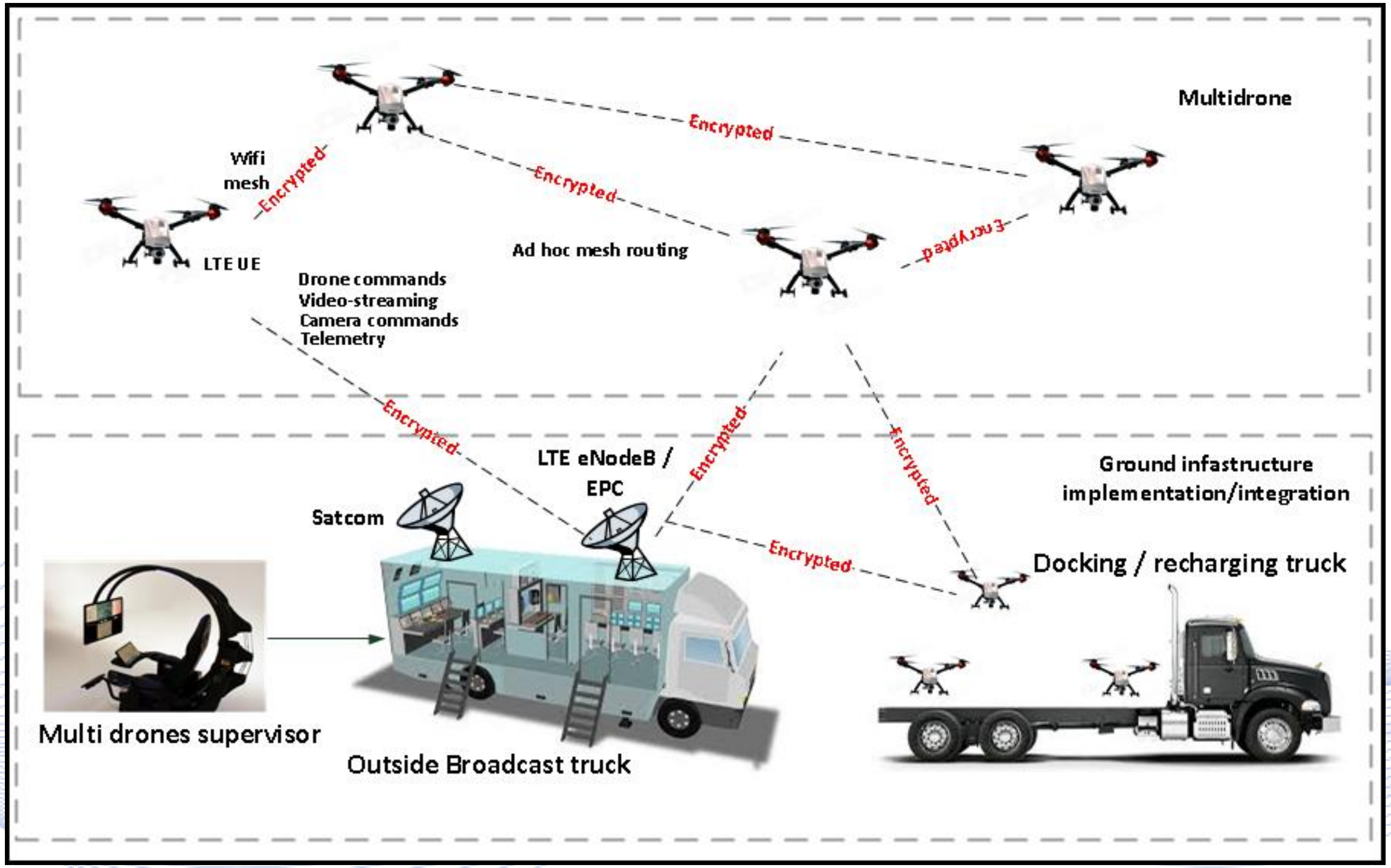


Autonomous system applications

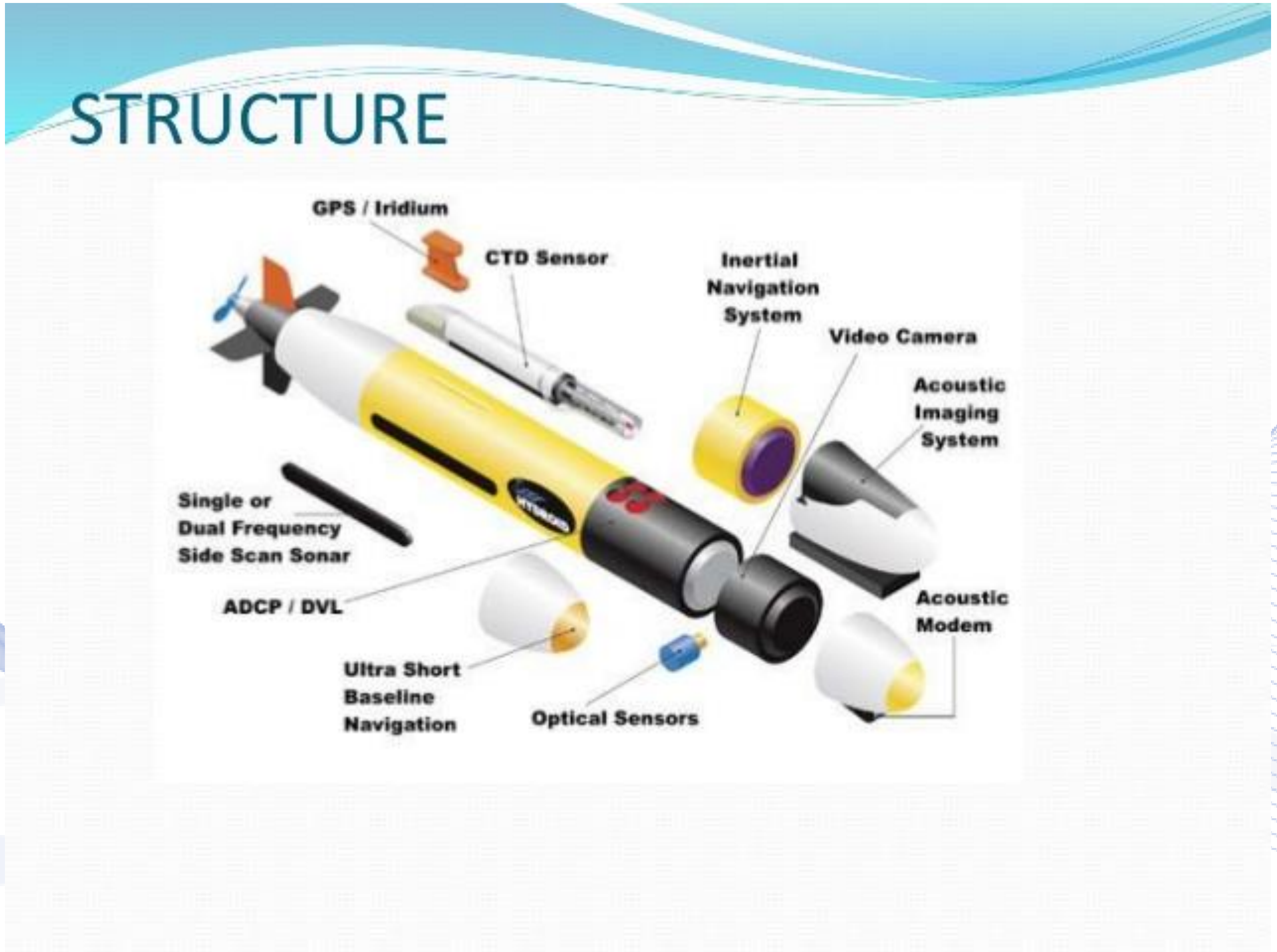
Drones



Autonomous system applications
Drone swarms



Autonomous system applications
Undewater vehicles

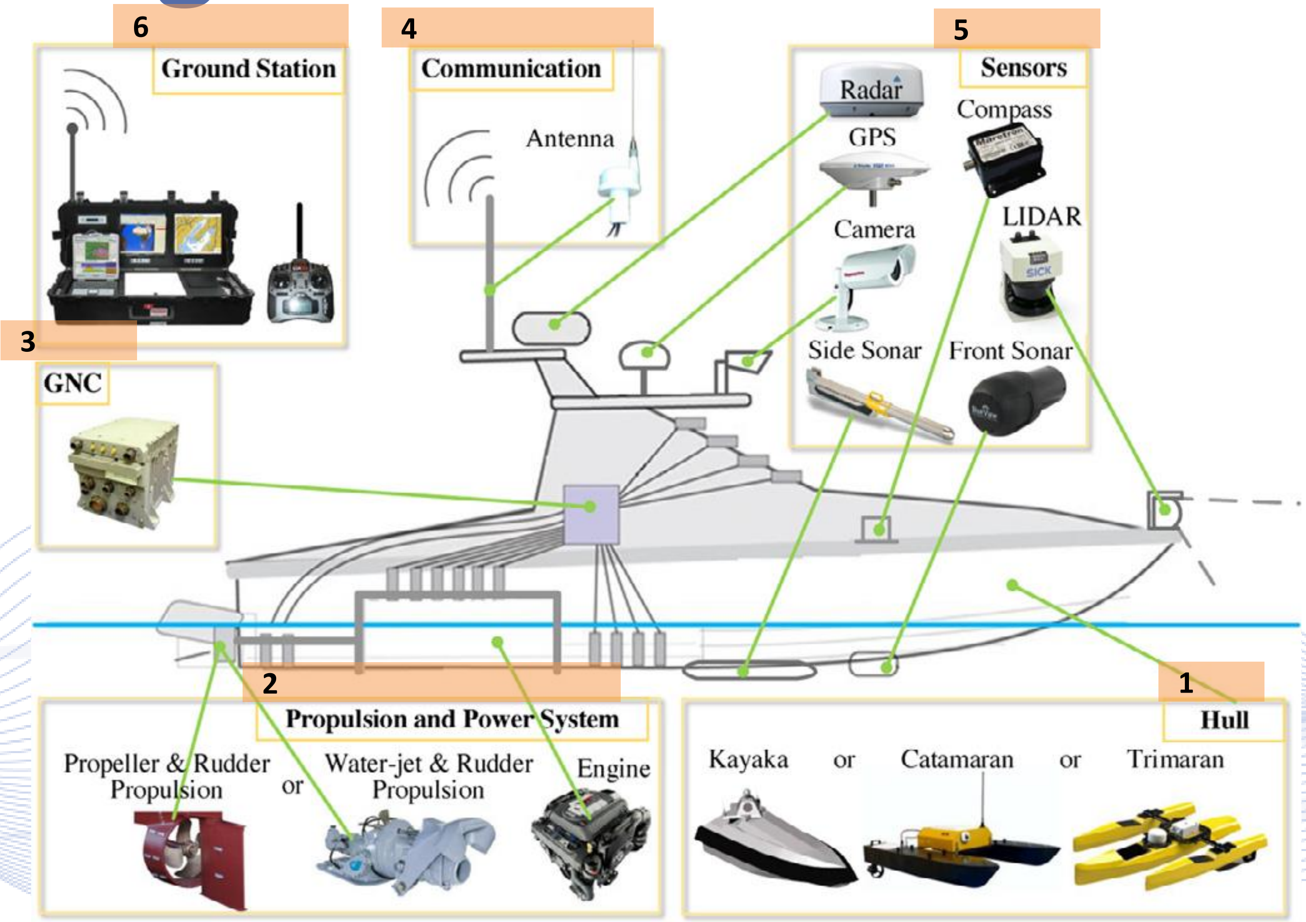


Autonomous system applications

Merchant ships

Autonomous system applications
Robots

Autonomous System technologies



Basic elements of an Autonomous Surface Vessel [LIU2016].

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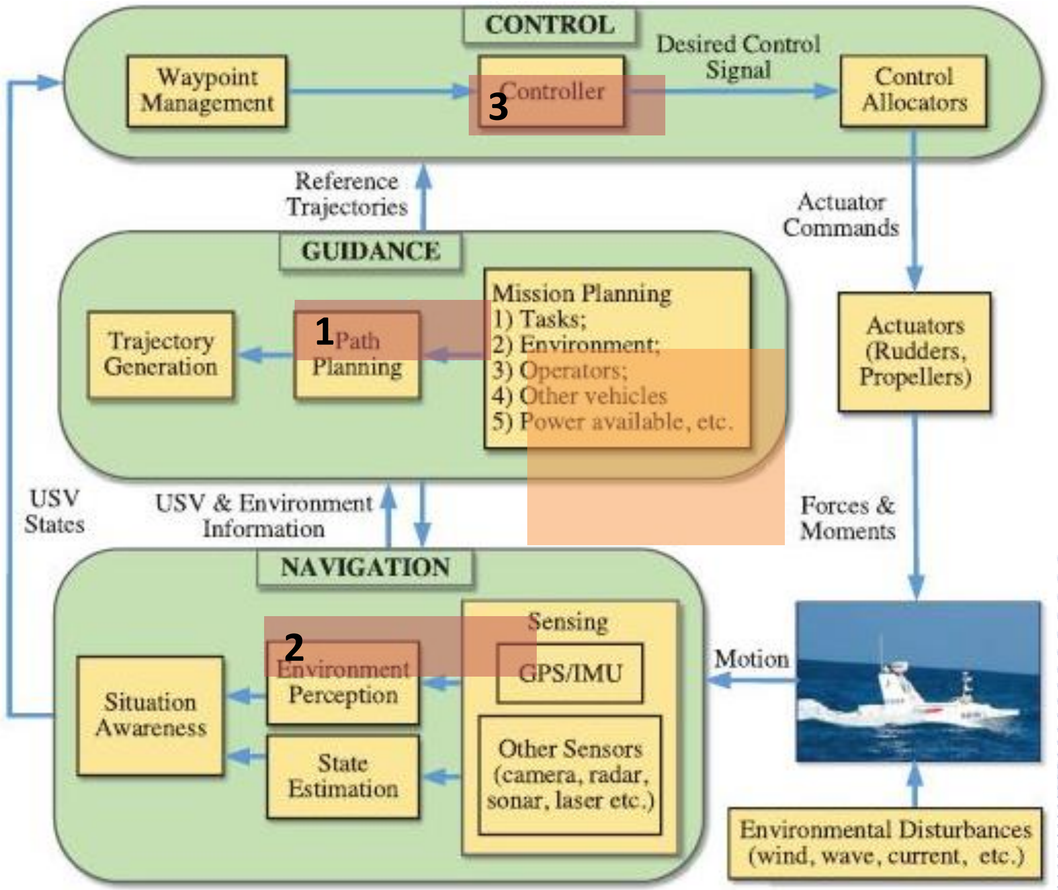
Autonomous System technologies



Autonomous Surface Vessel structure systems [LIU2016].

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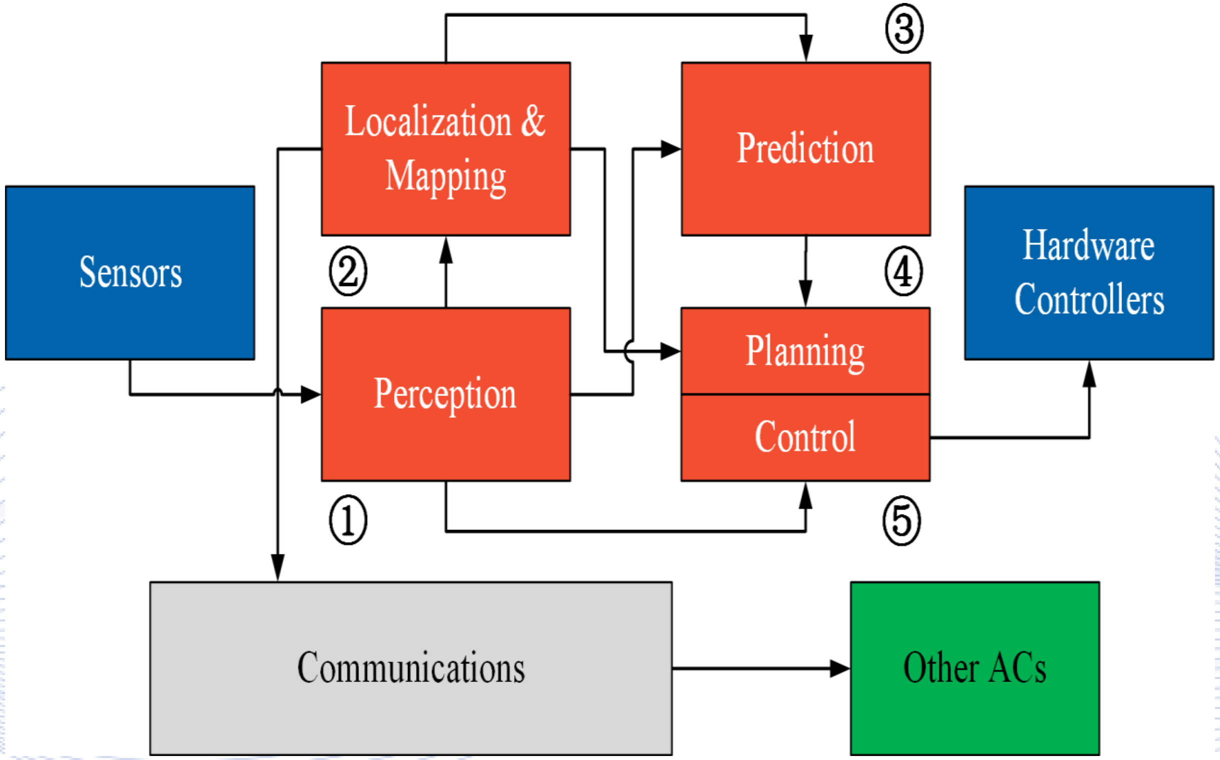
Autonomous System technologies

- Autonomous car structure



Autonomous System technologies

- **Mission Planning and Control**
- Perception and Intelligence
- Embedded computing
- Swarm systems
- Communications
- Societal technologies

Autonomous system mission

- **Autonomous car mission**
  - **List of navigation actions**
  - **Motion along a 2D trajectory (path)**
- **Autonomous drone AV Shooting Mission**: list of **actions**
  - **Shooting Actions**: drone + camera

    e.g., Lateral Tracking, Fly-Over, Orbit, …
  - **Navigation Actions**: drone action only, does not involve shooting

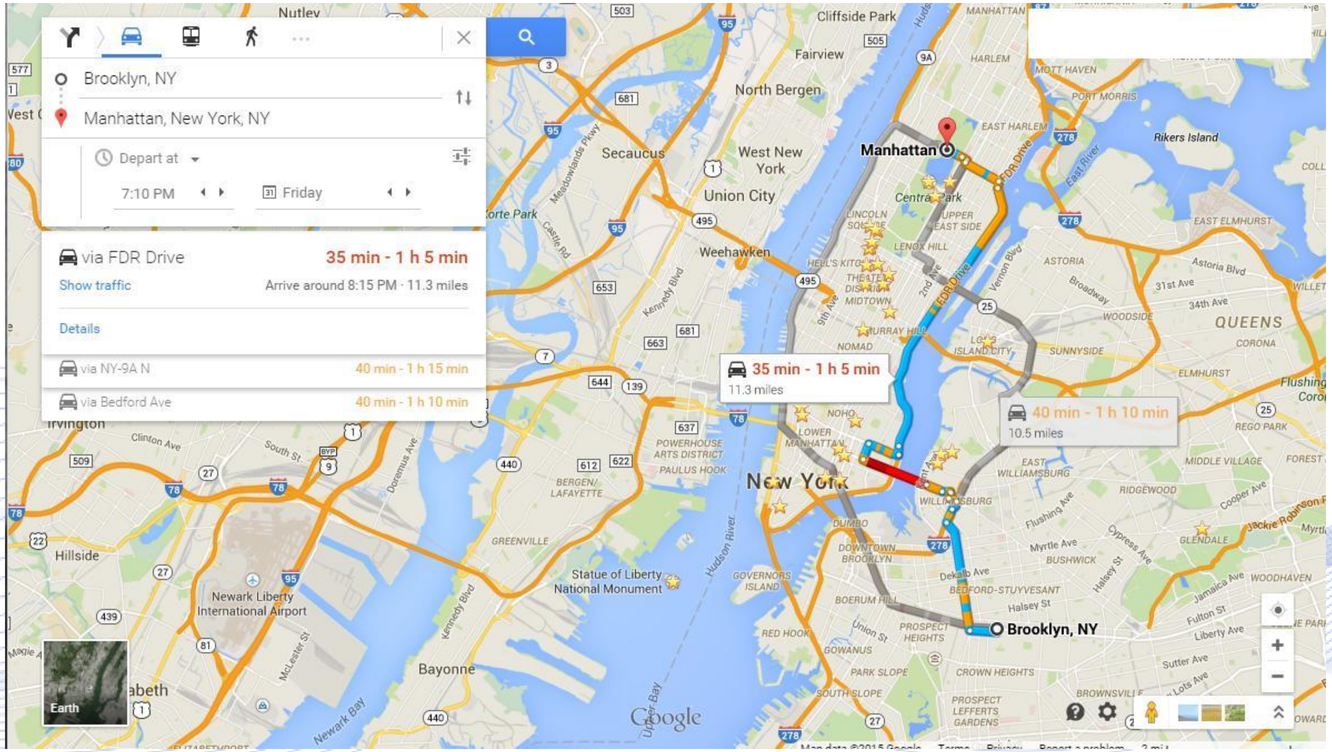
    e.g., Take-off, Land, Go-to-waypoint, …

Autonomous system mission planning

- **Autonomous car mission planning**
  - Find the best (2D) trajectory from start to destination
  - Planning constraints:
    - Road map (e.g., Google maps)
    - Regulatory restrictions (one way streets)
    - Traffic load
  - Use of semantic (2D) maps

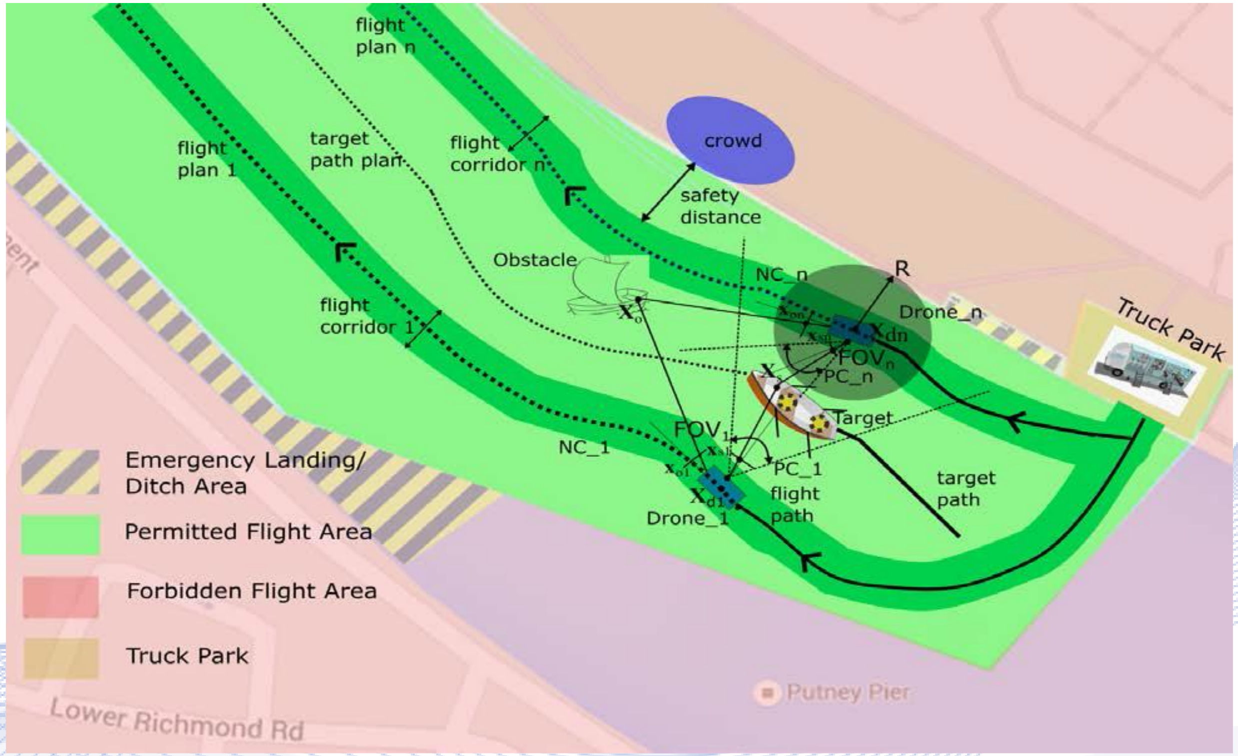
Autonomous system mission planning

- Google maps path planning.



Autonomous system mission planning

- Drone mission planning.
- Planning of:
  - Drone flight
  - Payload (e.g., camera) actions
- Use of semantic 3D maps



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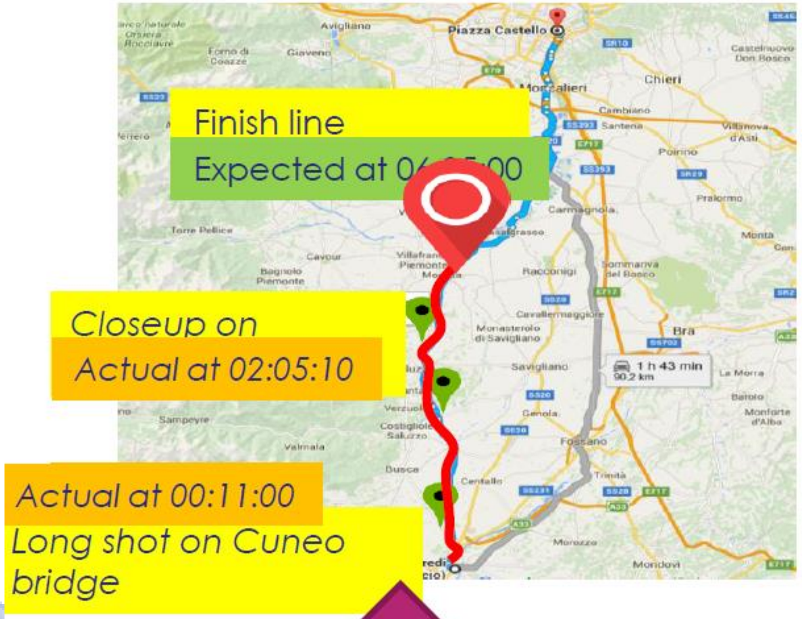
Mission example: Giro d'Italia



<<Accident Detected>>

Path Planner

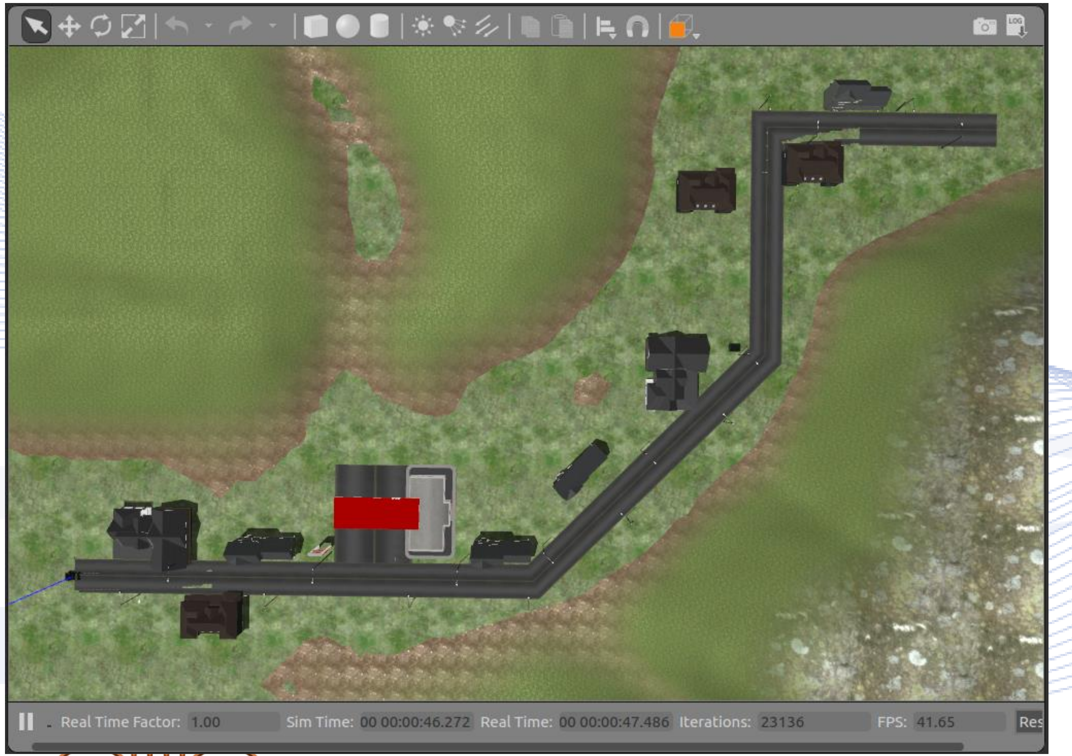
- This submodule is used by:
  - High-level Planner to estimate drone paths and flying times.
  - Onboard Scheduler to compute a path to a landing position in case of emergency.

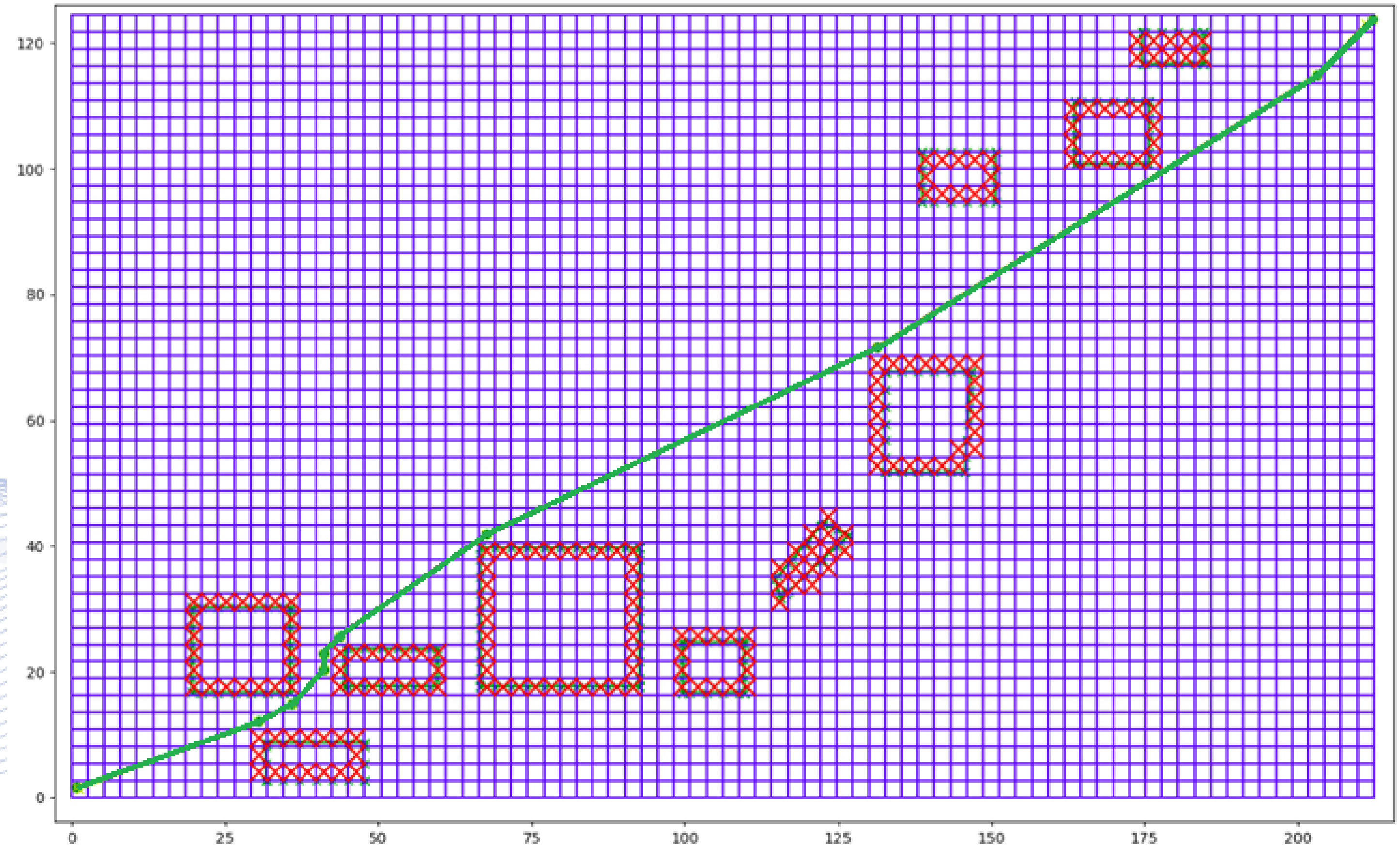
- Navigation map implemented as a grid. Obtained from Semantic Map.
  - Semantic annotations are indicated as KML features.
  - Geodesic coordinates translated into Cartesian.
  - No-fly poligons become occupied cells in grid.

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

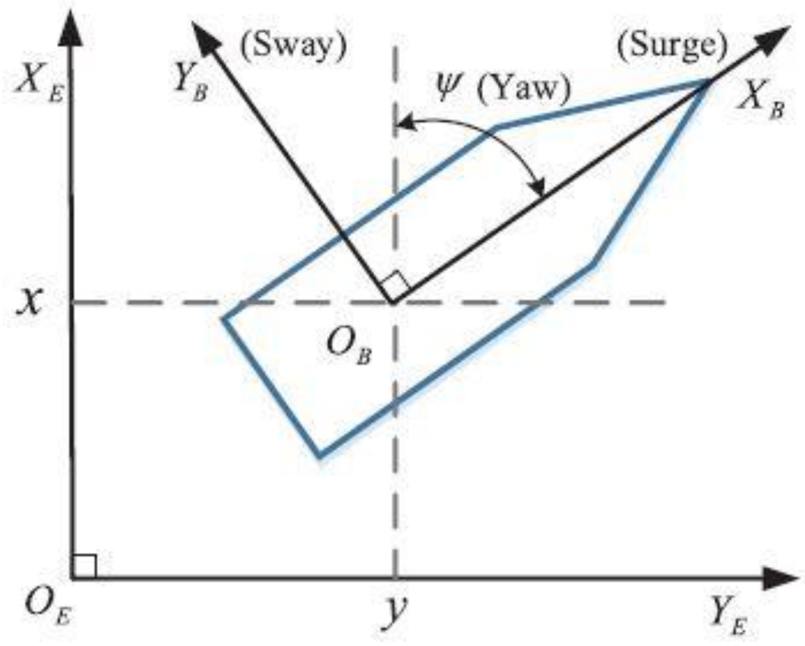
Path Planner Example

- 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.





Autonomous vehicle control



ASV planar motion [LIU2016].

Autonomous vehicle control is based on:

- Kinematic vehicle model
- dynamic vehicle model.

They are drastically vehicle-dependent.

Autonomous Surface Vessel (ASV):

- kinematic (motion) model:

$$\dot{\boldsymbol{\eta}} = \mathbf{R}(\psi)\boldsymbol{\nu}.$$

- dynamic model [FOS1994]:

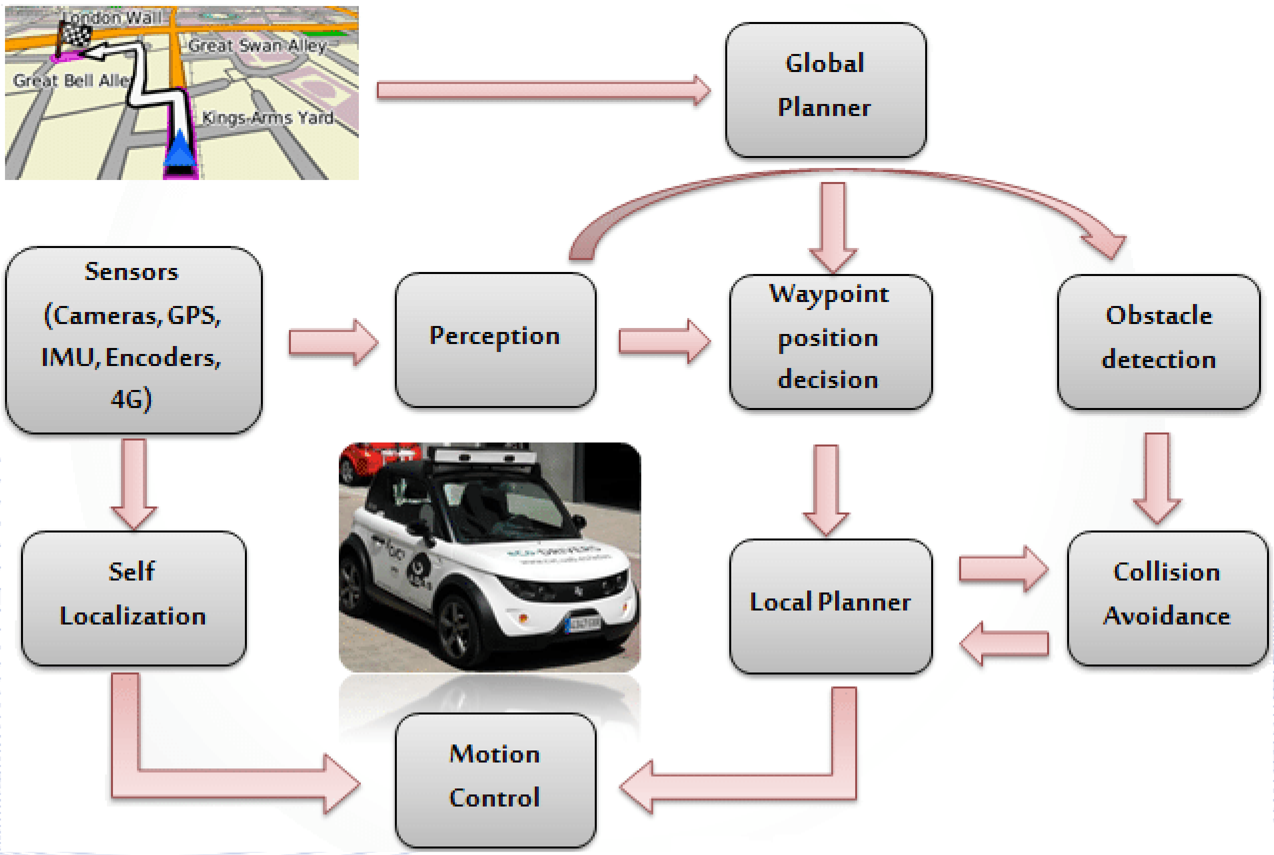
$$\mathbf{M}\dot{\mathbf{v}} + \mathbf{C}(\mathbf{v})\mathbf{v} + \mathbf{D}(\mathbf{v})\mathbf{v} + \mathbf{g}(\eta) = \boldsymbol{\tau} + \boldsymbol{\tau}_{\mathbf{E}}.$$

Autonomous car control

- Car dynamic modelling
- Interfacing car perception to car control
- Levels of car control automation

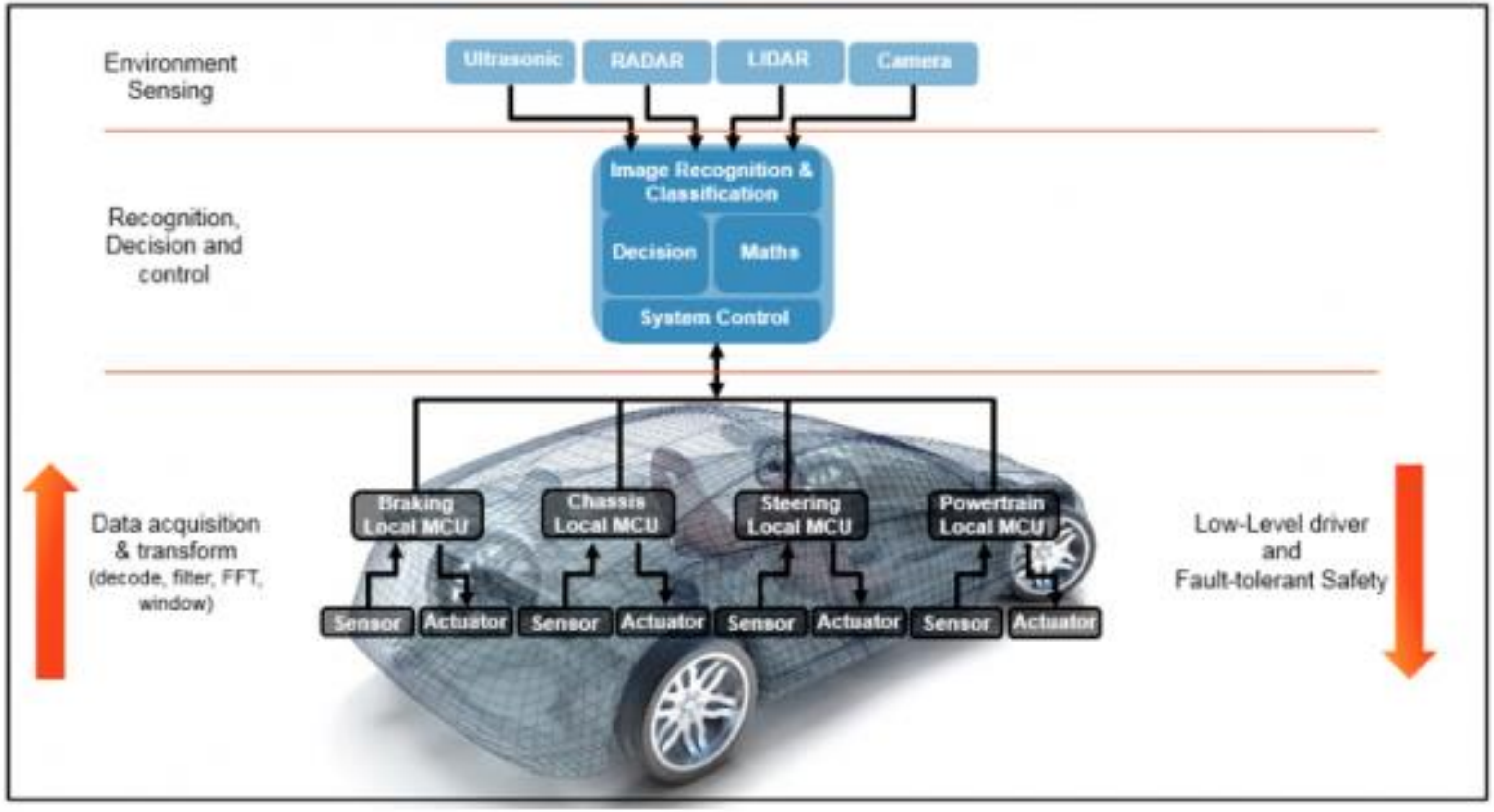
Level	Name	Driver	DEM2	DDTF3
0	No automation	HD4	HD	HD
1	Driver assistance	HD & system	HD	HD
2	Partial automation	System	HD	HD
3	Conditional automation	System	System	HD
4	High automation	System	System	System
5	Full automation	System	System	System

Autonomous car control



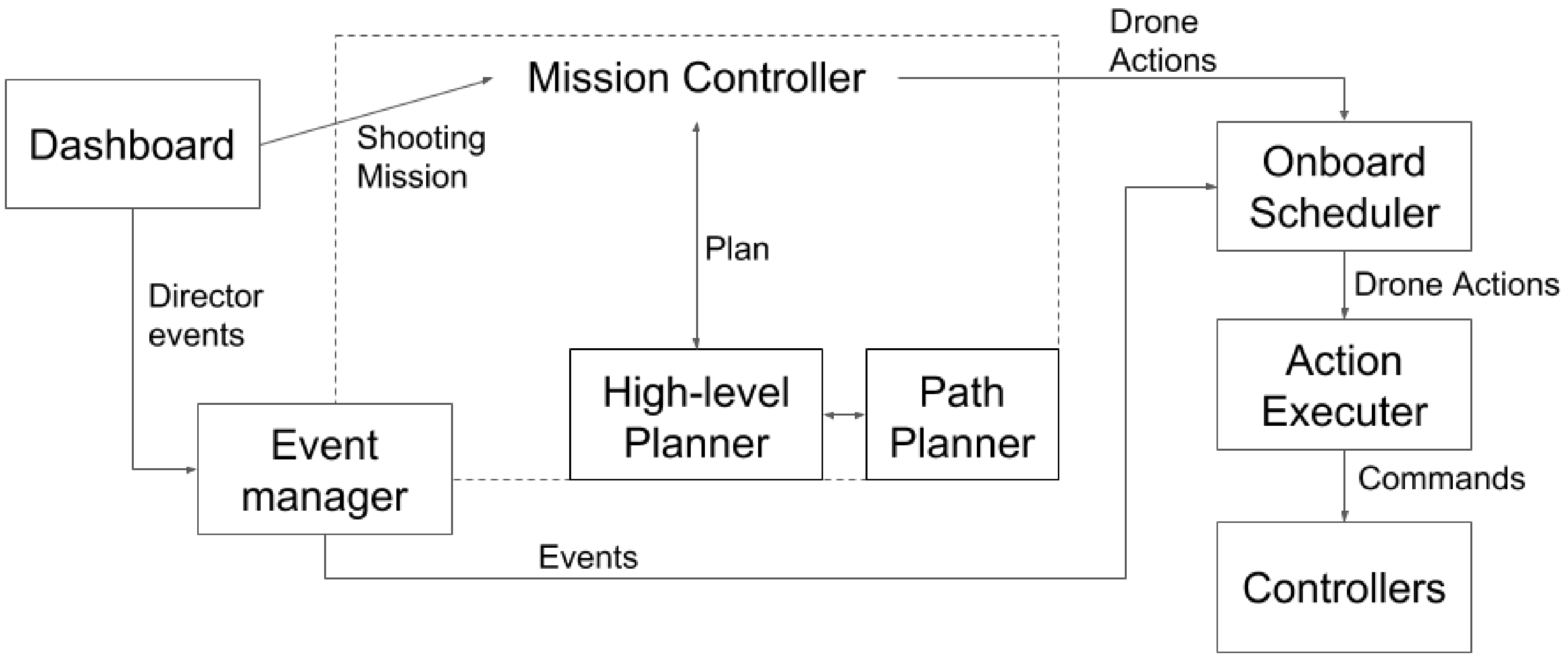
Autonomous car control

- Steering control
- Braking control
- Power control



Drone Mission Planning and Control Architecture

MULTIDRONE Planning



Drone Control Objectives – Trajectory Tracking

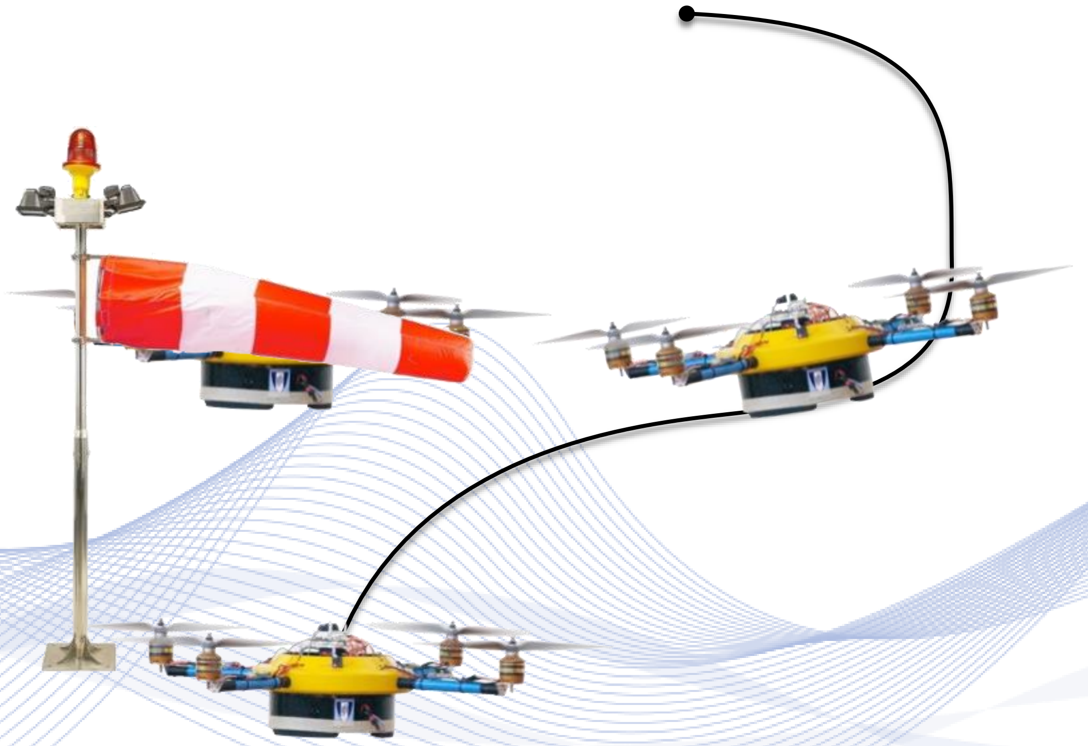
Track a trajectory.

Realistic model.

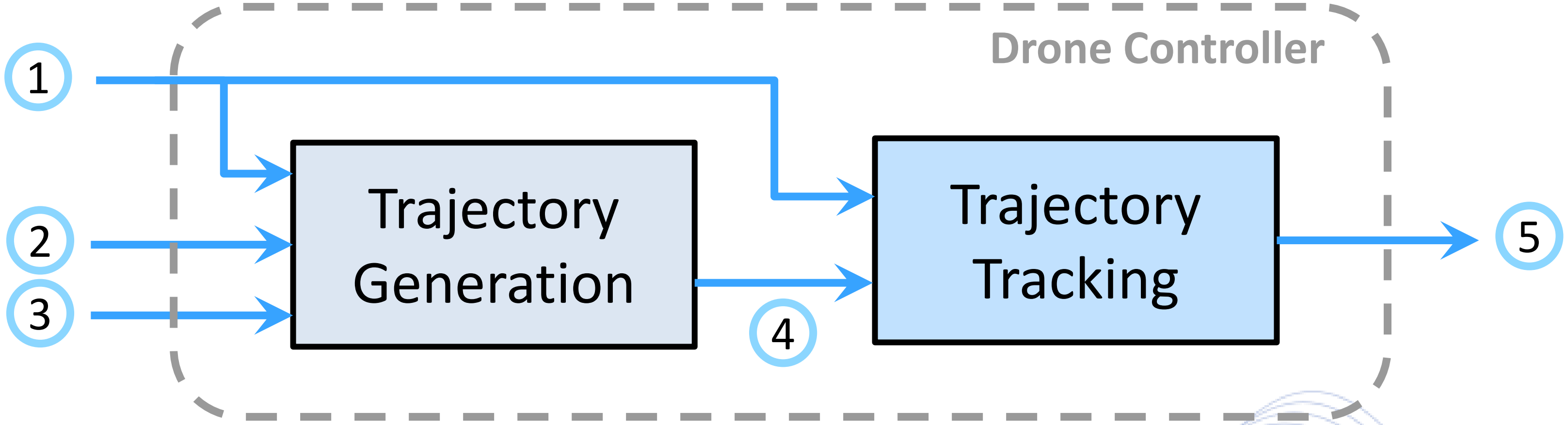
Robustness to disturbances.

Bounded actuation.

Large basin of attraction.



Drone Controller



1 Drone Status

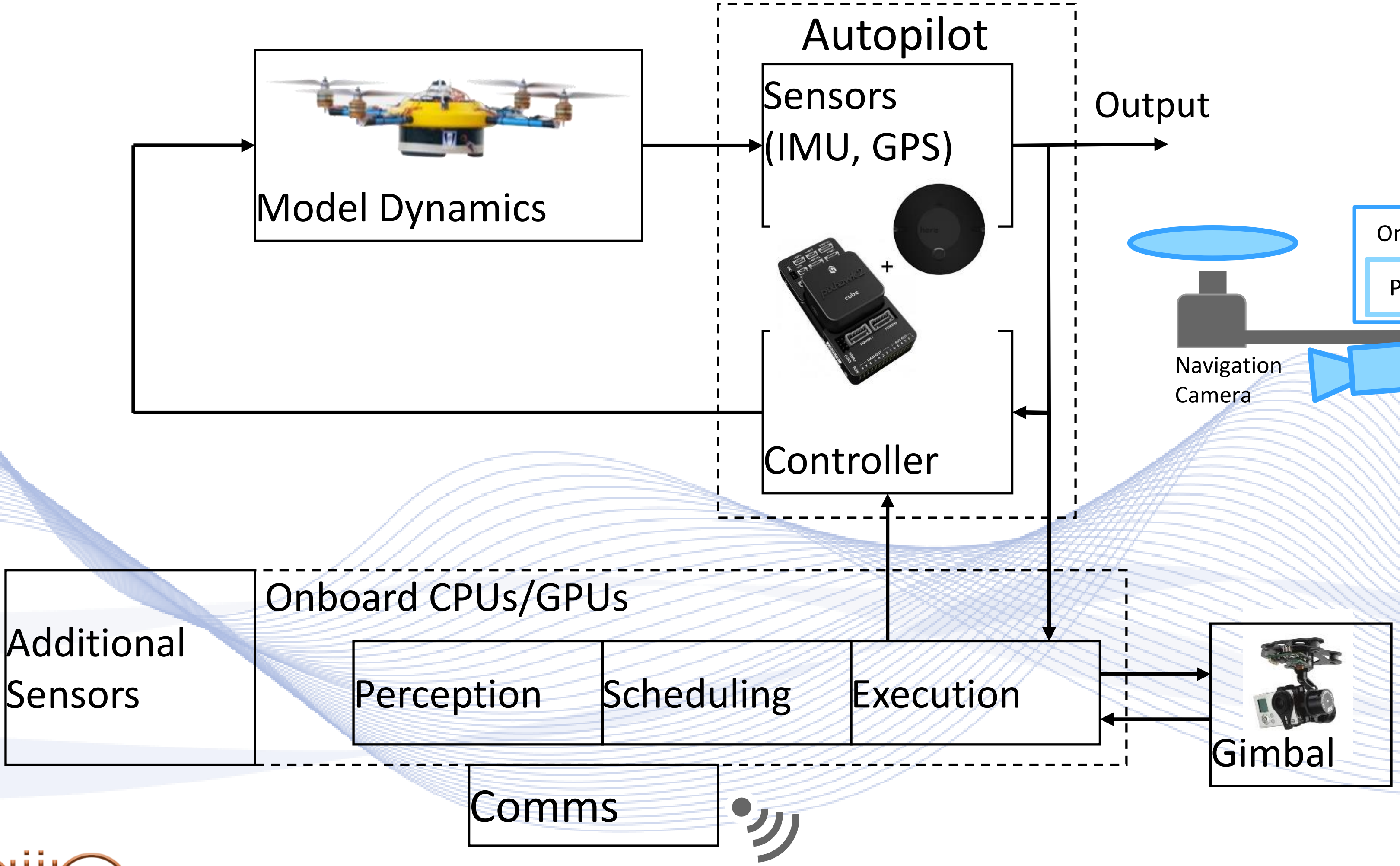
2 Target Status

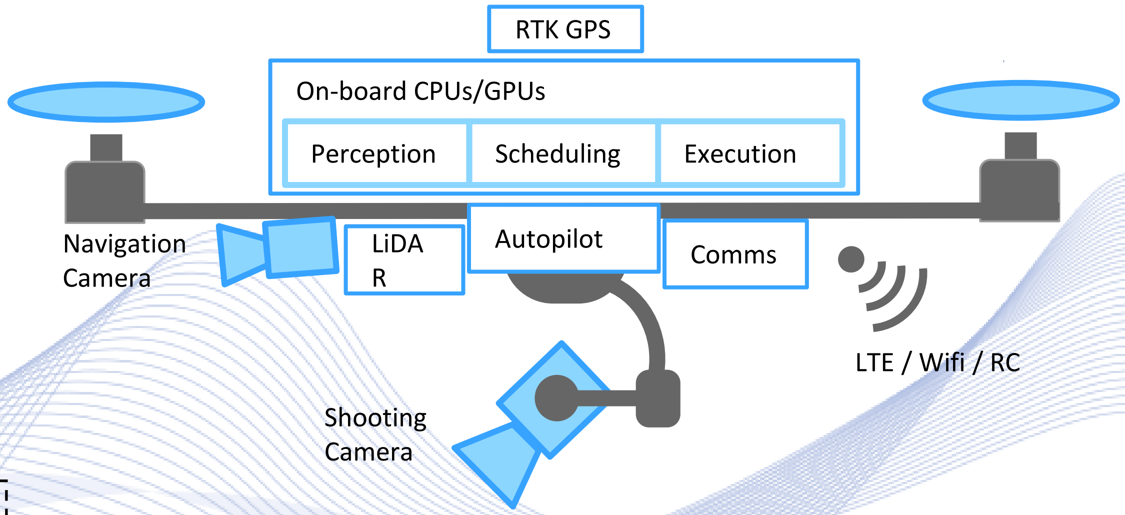
3 Shooting Action parameters

4 Reference

5 Drone Velocity Command

Onboard Drone control Architecture





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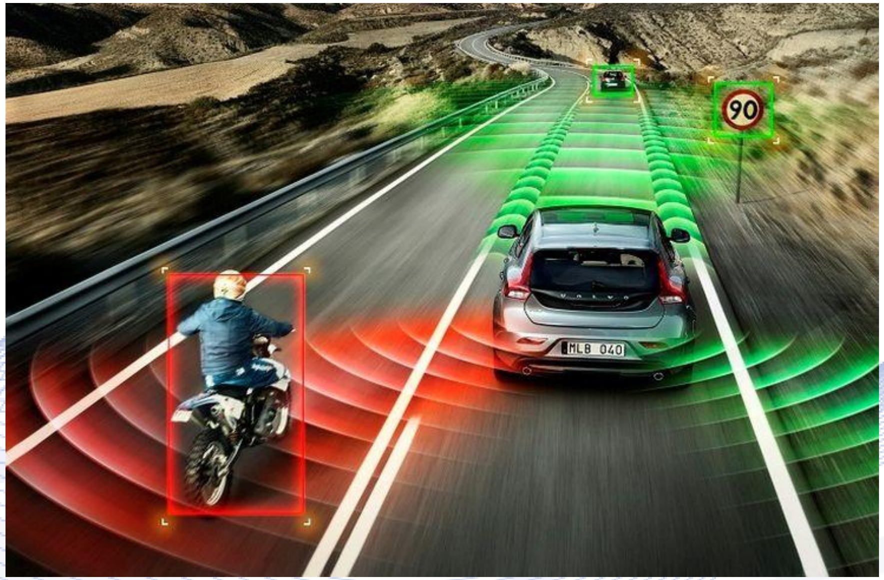
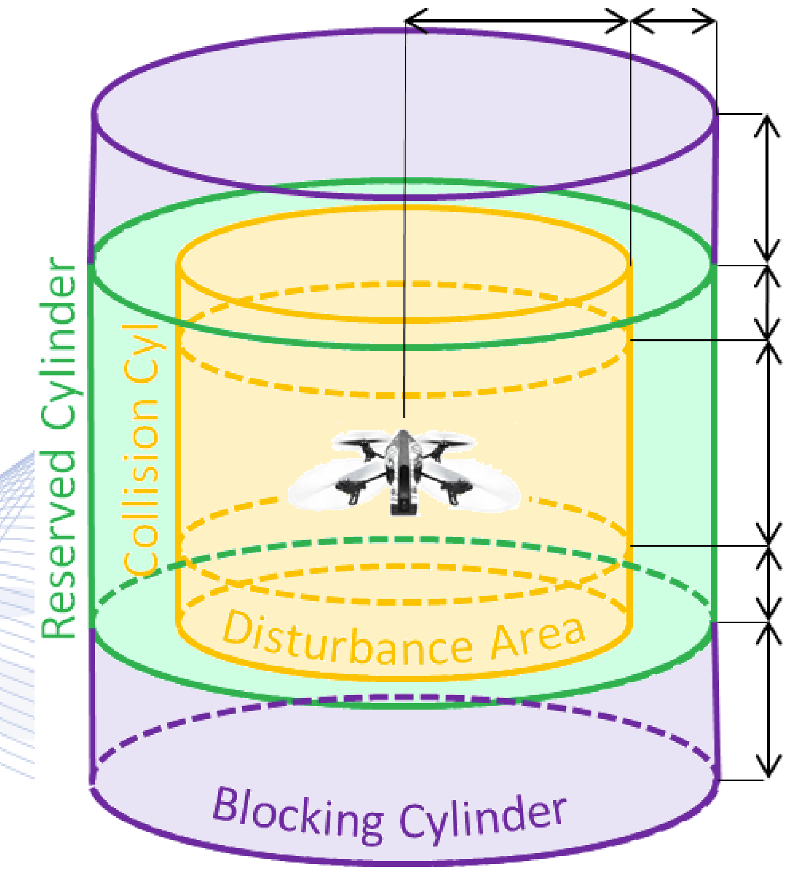
Car collision avoidance

- Sensors for:
- Vehicle detection/localization
- Pedestrian detection
- Real-time car trajectory replanning for collision avoidance.



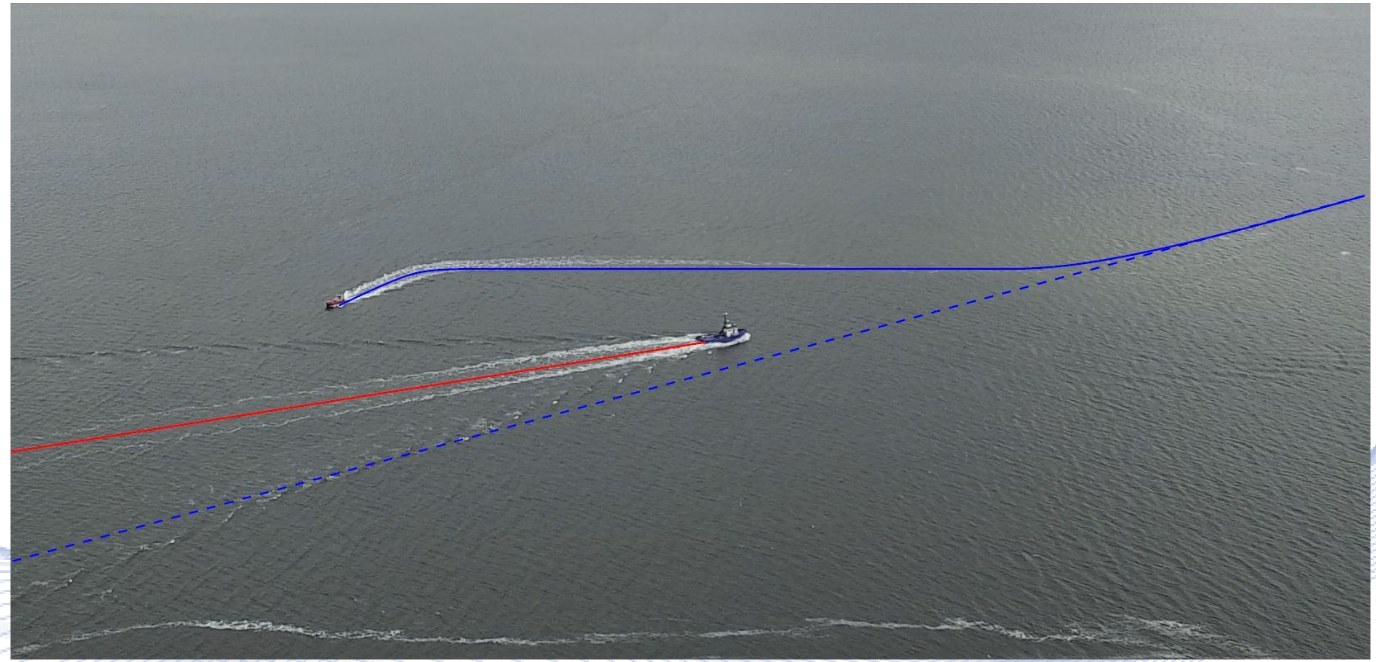
Drone collision avoidance

- Collision hull defined as a cylinder (yellow).
- Horizontal conflict when reserved 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.



AVS collision avoidance

Autonomous surface vessel Collision avoidance: Autosea project



Example of AVS collision avoidance [AUT].

Autonomous System technologies

- Mission Planning and Control
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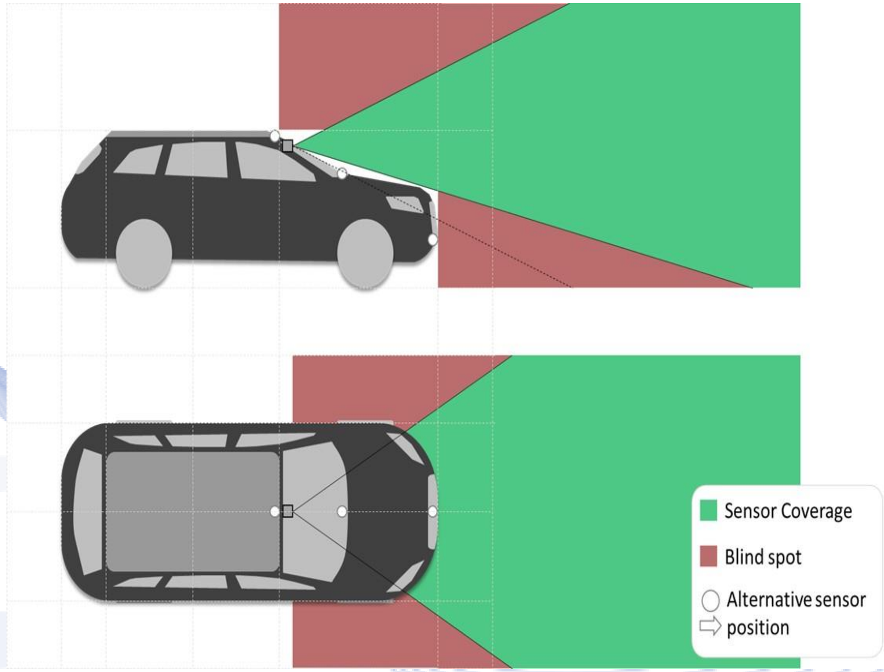
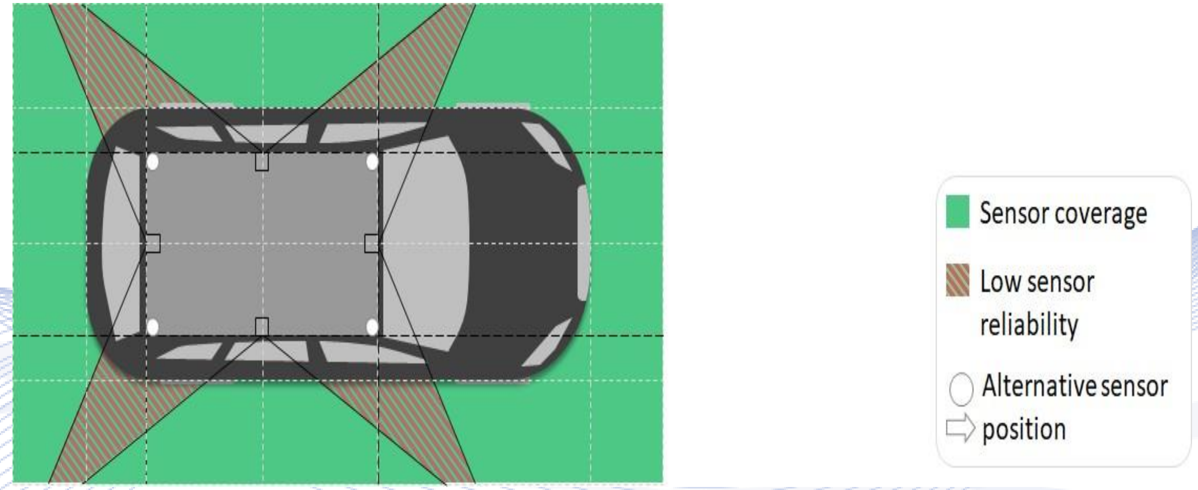
Autonomous car sensors

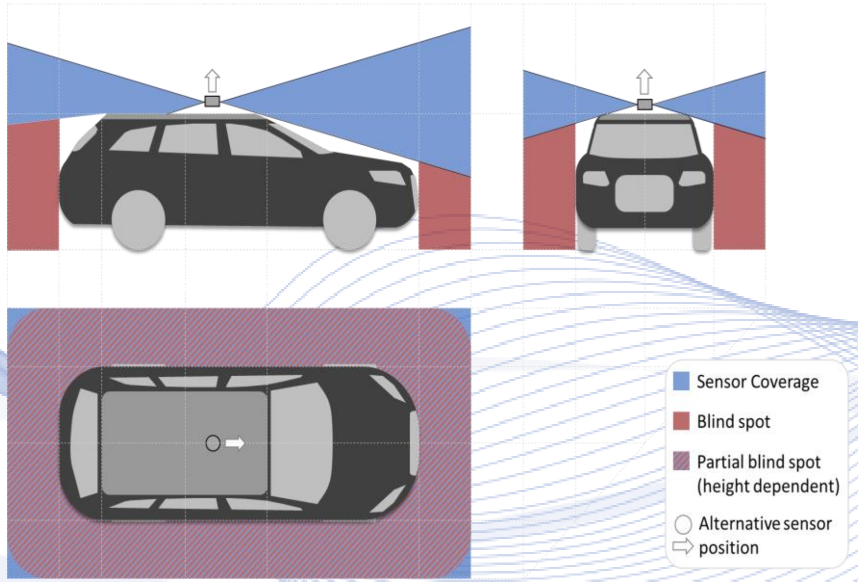
- Front/roof cameras

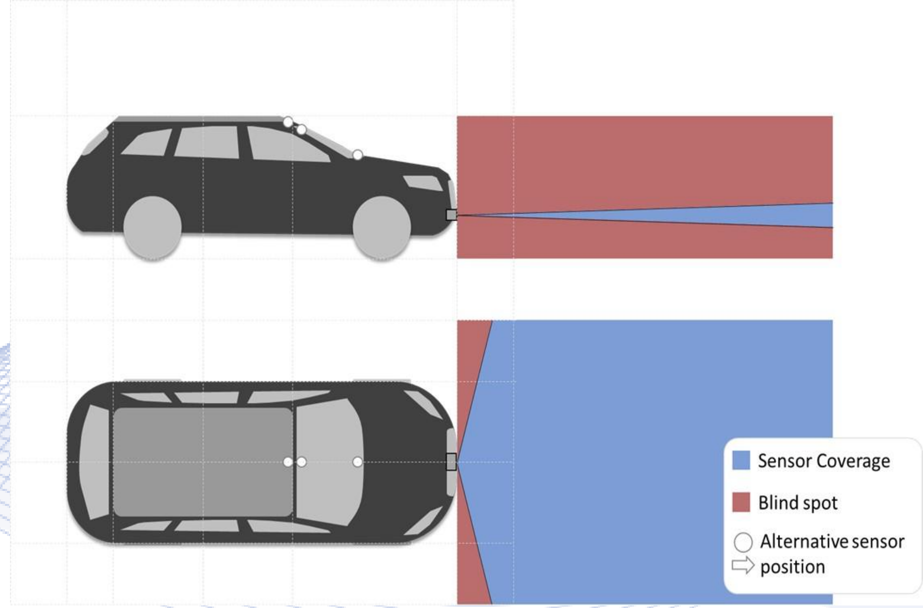




Autonomous car sensors

- Front/roof Lidars





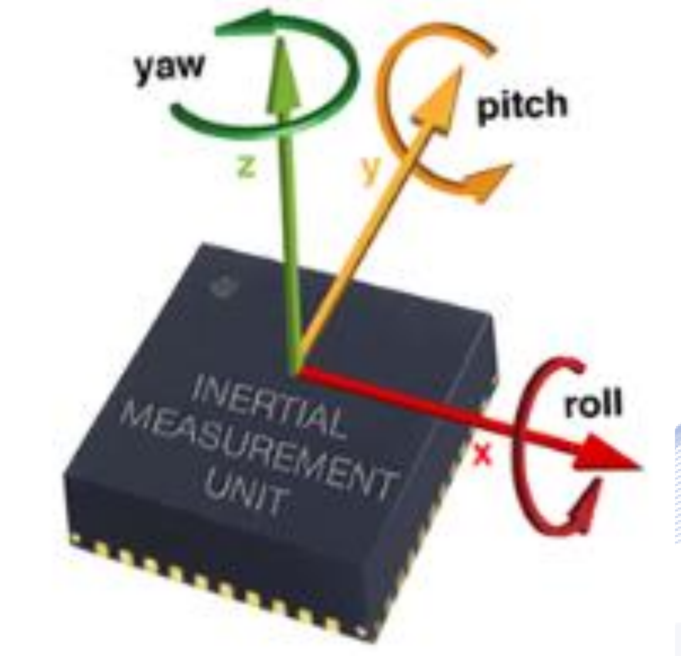
3D localization sensors: GPS

- Other Satellite systems: GLONASS (Russia), BeiDou (China), Galileo (EU).
- ***RTK-GPS*** uses measurements of the phase of the signal carrier wave, in addition to the information content of the signal and relies on a single reference ground station (or interpolated virtual station) to provide real-time corrections, providing up to cm-level accuracy.

Drone Sensors: IMU

- ***Inertial Measurement Unit (IMU)***:
  - It measures and reports a body's specific force, angular motion rate and, sometimes, the magnetic field surrounding the body.

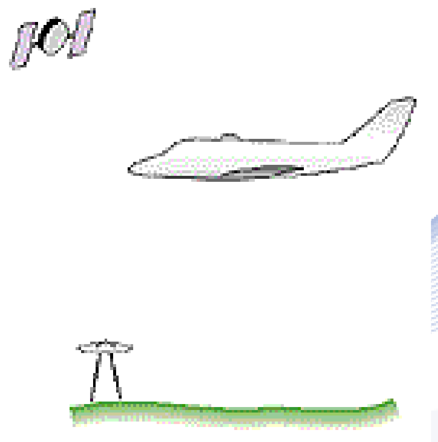
  - It uses a combination of **accelerometers**, **gyroscopes** and, sometimes, also magnetometers.



Drone Sensors: Laser altimeter

Laser altimeter:

- It measures the altitude (height) above a fixed ground level.
- It emits laser pulses which travel to the ground surface, where they are reflected.
- Part of the reflected radiation returns to the laser altimeter, is detected, and stops a time counter started when the pulse was sent out.
- The distance is then easily calculated by taking the speed of light into consideration.

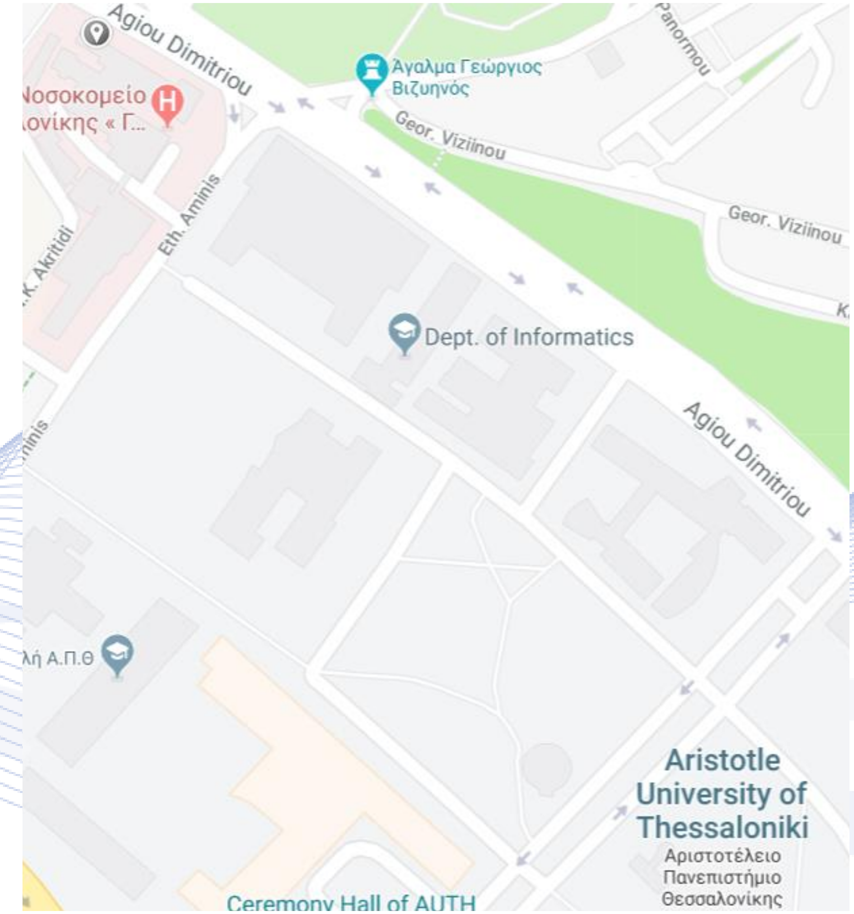


2D maps

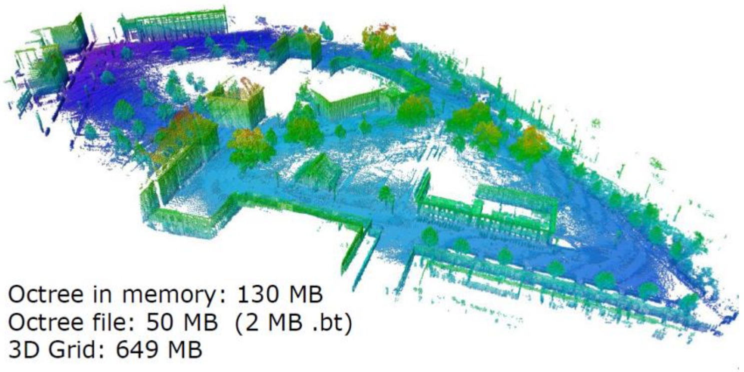
- ***Google maps.***
- ***OpenStreetMaps.***

- Semantic annotated information:
  - (roads, POIs, landing sites) in KML format in Google Maps.
  - roads in OSM (XML) in case of OpenStreetMaps.

- ***Google Maps JavaScript API.***
- ***OpenStreetMaps API.***



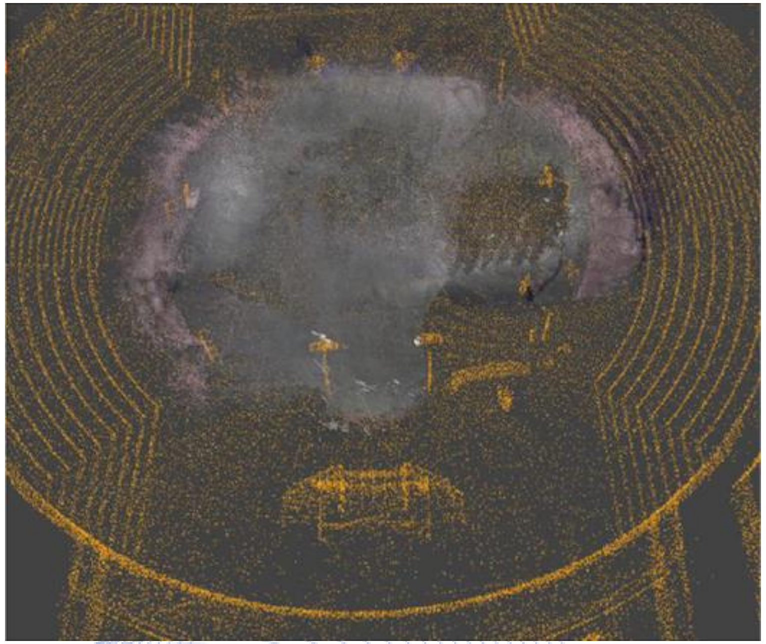
3D maps



- Formats:
    - 3D triangle mesh.
    - 3D Octomap.
- ***Octomap***:
    - The octomap is a fully 3D model representing the 3D environment, where the UAV navigates.
    - It provides a volumetric representation of space, namely of the occupied, free and unknown areas.
    - It is based on octrees and using probabilistic occupancy estimation.

Geometrical mapping

Lidar mapping

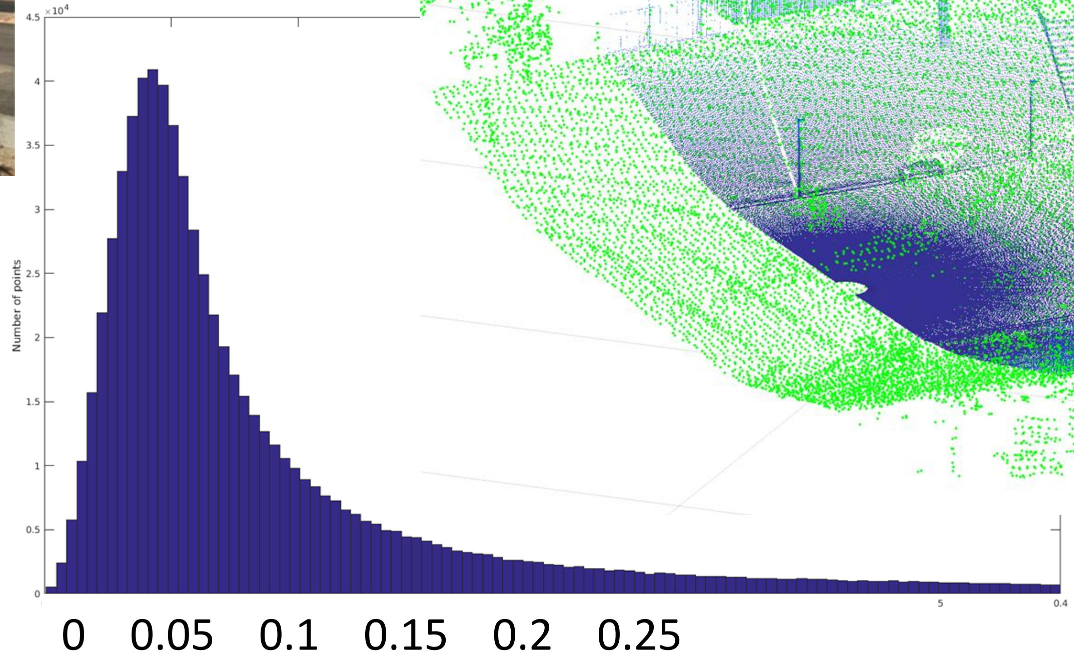


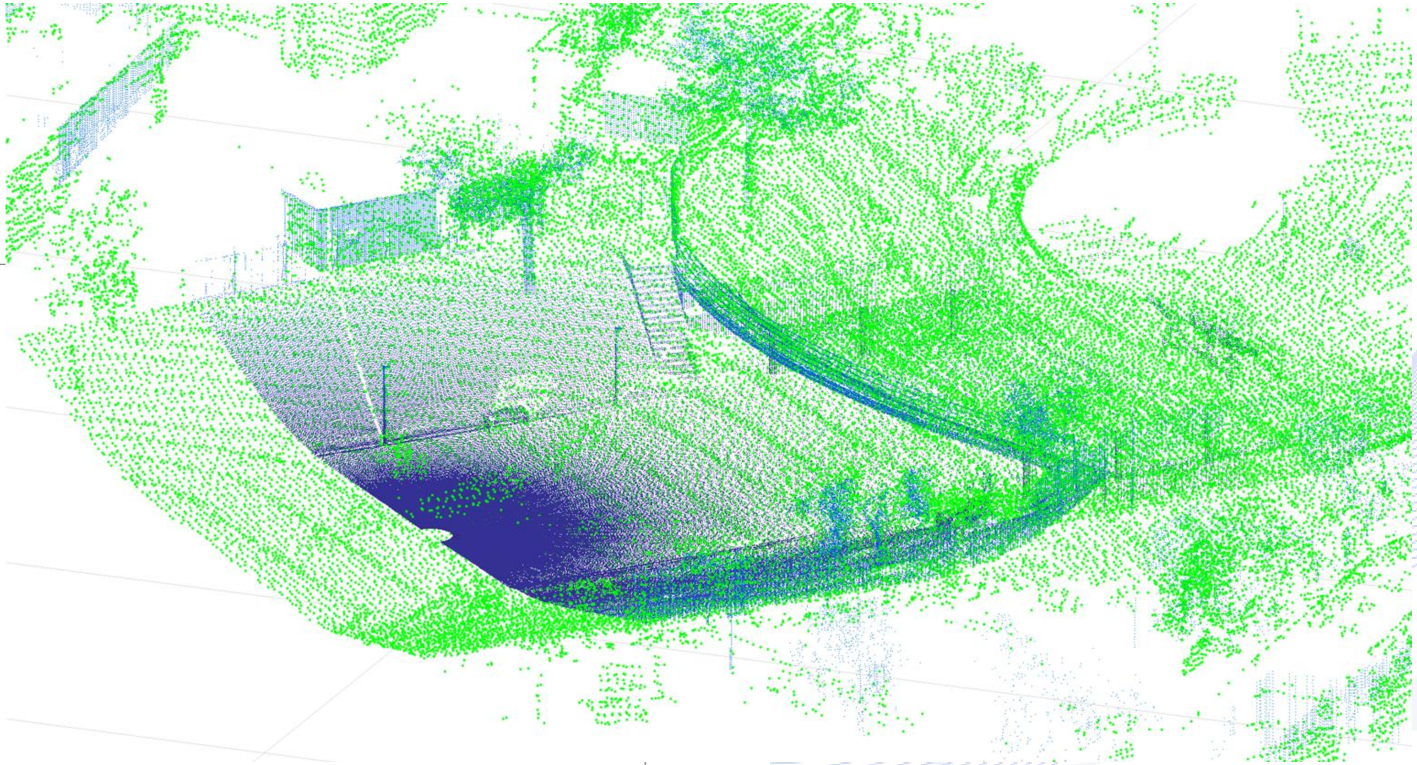
Repeatability

Dataset	Mean Error (m)	Median Error (m)	Min Error (m)
1	0,1377	0,1073	0,00098
2	0,1053	0,0769	0,00045
3	0,0847	0,0578	0,00083
4	0,1074	0,0792	0,00078
5	0,1722	0,1560	0,00130

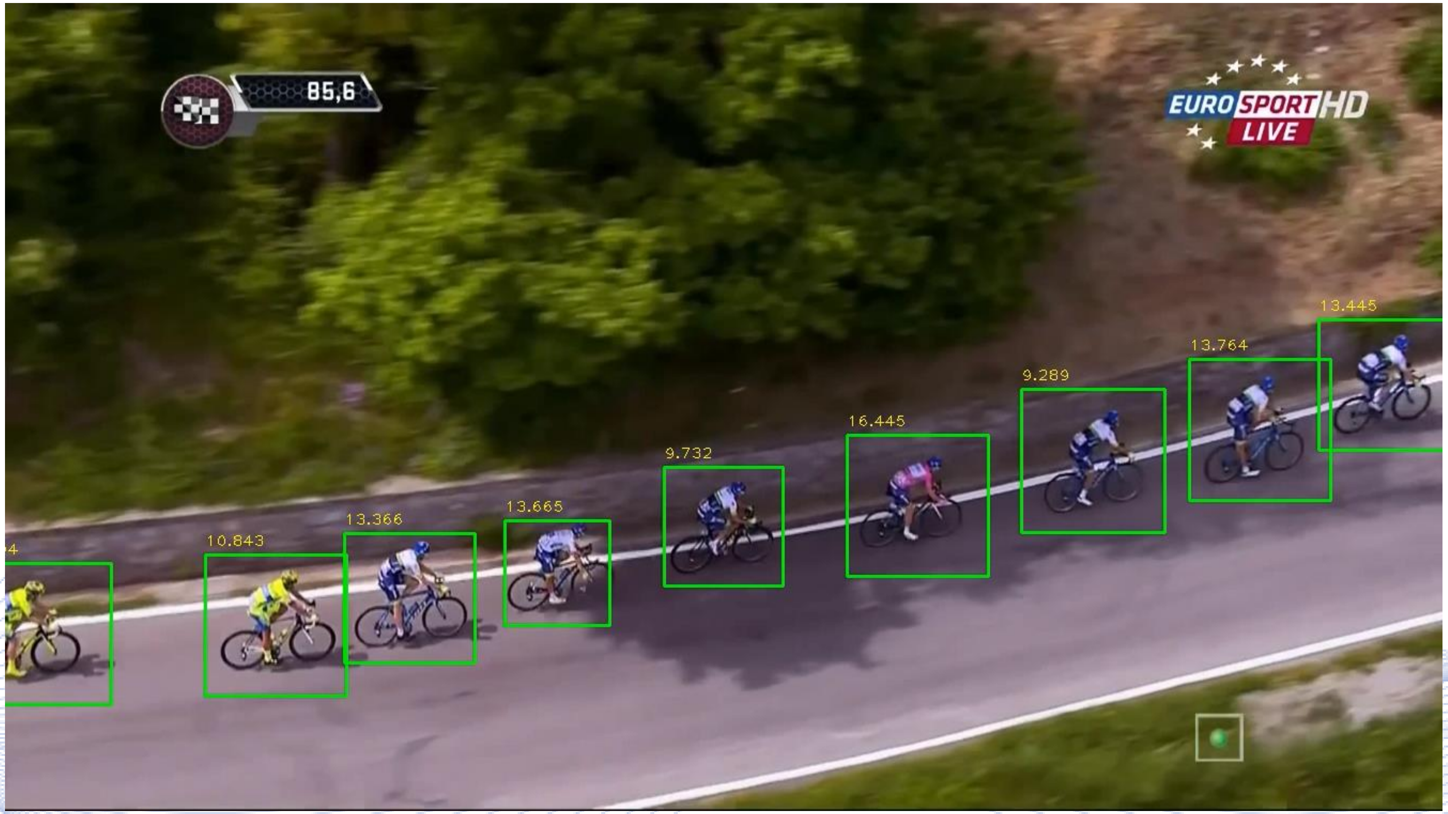
Geometrical mapping

Validation with a TOTAL STATION





UAV Object detection & tracking



Advanced autonomous car Intelligence

- Self-awareness
- Driver status modelling/recognition
- Affective computing
- Attention
- Human (e.g., pedestrian) intention prediction

Autonomous System technologies

- Mission Planning and Control
- Perception and Intelligence
- **Embedded computing**
- Swarm systems
- Communications
- Societal technologies

GPU and multicore CPU architectures. Algorithm mapping

- **NVIDIA embedded processing boards**
  - NVIDIA Jetson TX2
  - **NVIDIA Jetson Xavier**
- GPU and multicore CPU architectures
      - » Multicore CPUs
    - – GPUs
- Algorithm mapping:

  Convolutions

GPU and multicore CPU architectures. Algorithm mapping

- NVIDIA embedded processing boards
- NVIDIA Jetson TX2
- NVIDIA Jetson Xavier
- **GPU and multicore CPU architectures**
    - **Multicore CPUs**
    - GPUs
- Algorithm mapping:

  Convolutions

Processing Units

- **Multicore (CPU):**
  MIMD.
  Focused on latency.
  Best single thread performance.
- **Manycore (GPU):**
  SIMD.
  Focused on throughput.
  Best for embarrassingly parallel tasks.

NVIDIA Jetson Xavier

- AI Computer for autonomous machines
- Designed for robots, drones and other
- Multiple operating modes (10/15/30 W)
- Comparison to TX2:

    Greater than 10x the energy efficiency.

    More than 20x the performance

CUDA

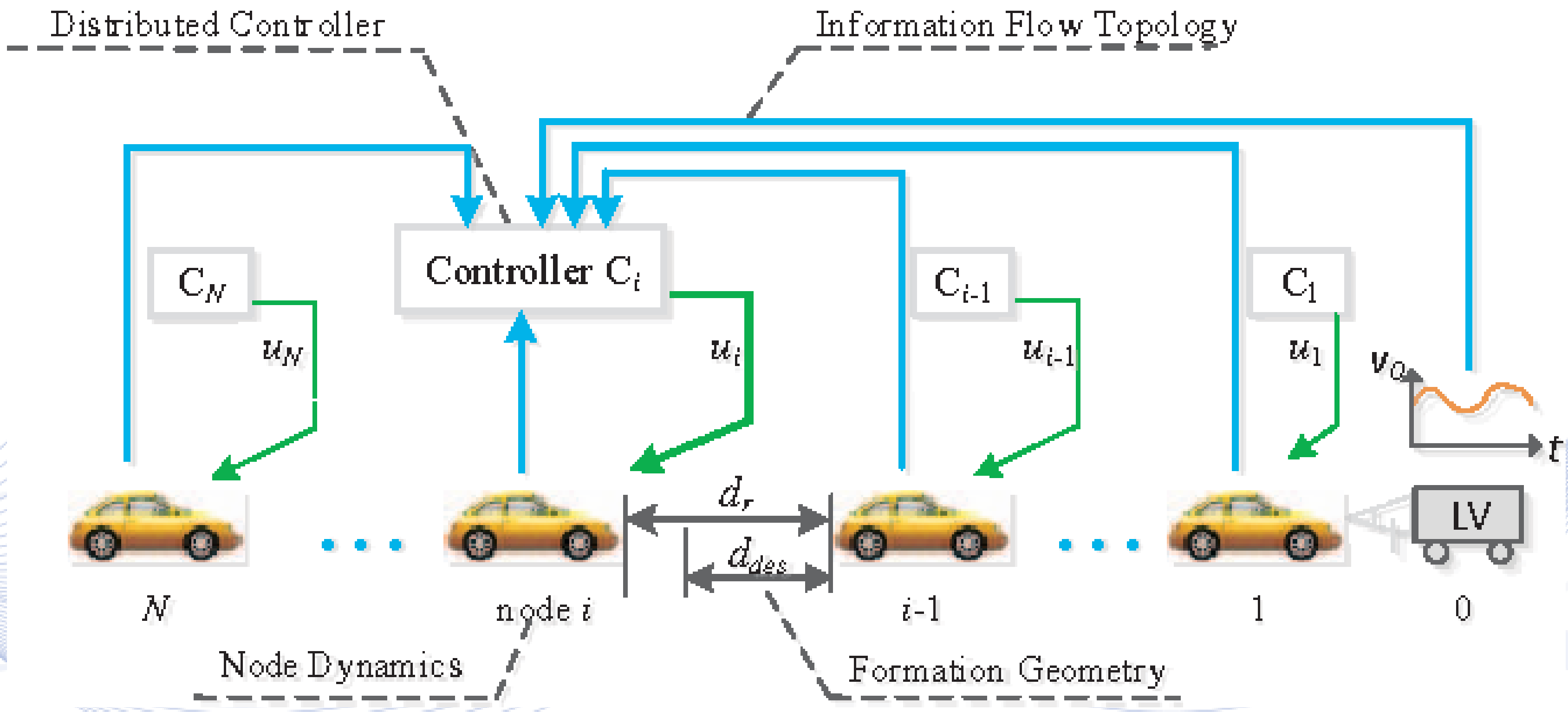
- Compute Unified Device Architecture (CUDA) is a parallel programming framework.
- Developed by Nvidia.
- Started as an attempt to give C/C++ programs access to GPU resources.
- Microarchitectures are name after famous physicists (Kepler, Maxwell, Pascal, Turing, Volta).

Autonomous System technologies

- Mission Planning and Control
- Perception and Intelligence
- Embedded computing
- **Swarm systems**
- Communications
- Societal technologies

Autonomous Systems swarms

- Car platoon control



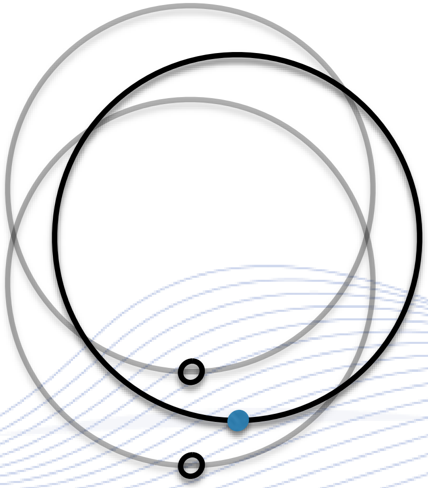
Autonomous Systems swarms

- Lane-less highways
- Collision avoidance
- Fluid dynamics principles

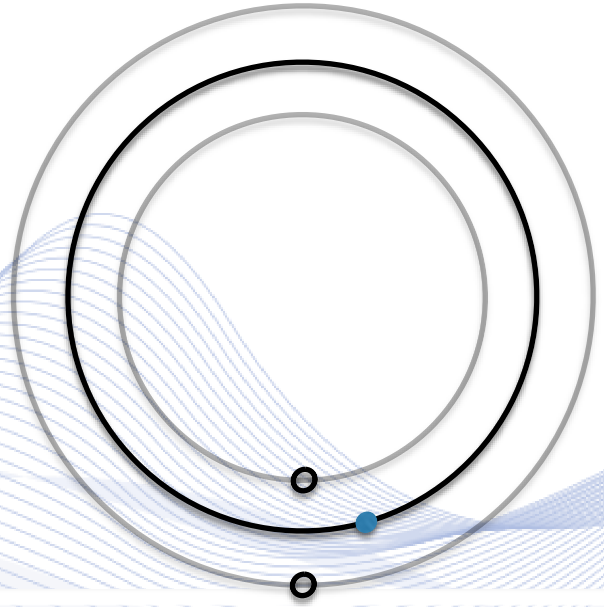
Drone swarms

Leader-following for drone formation control

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

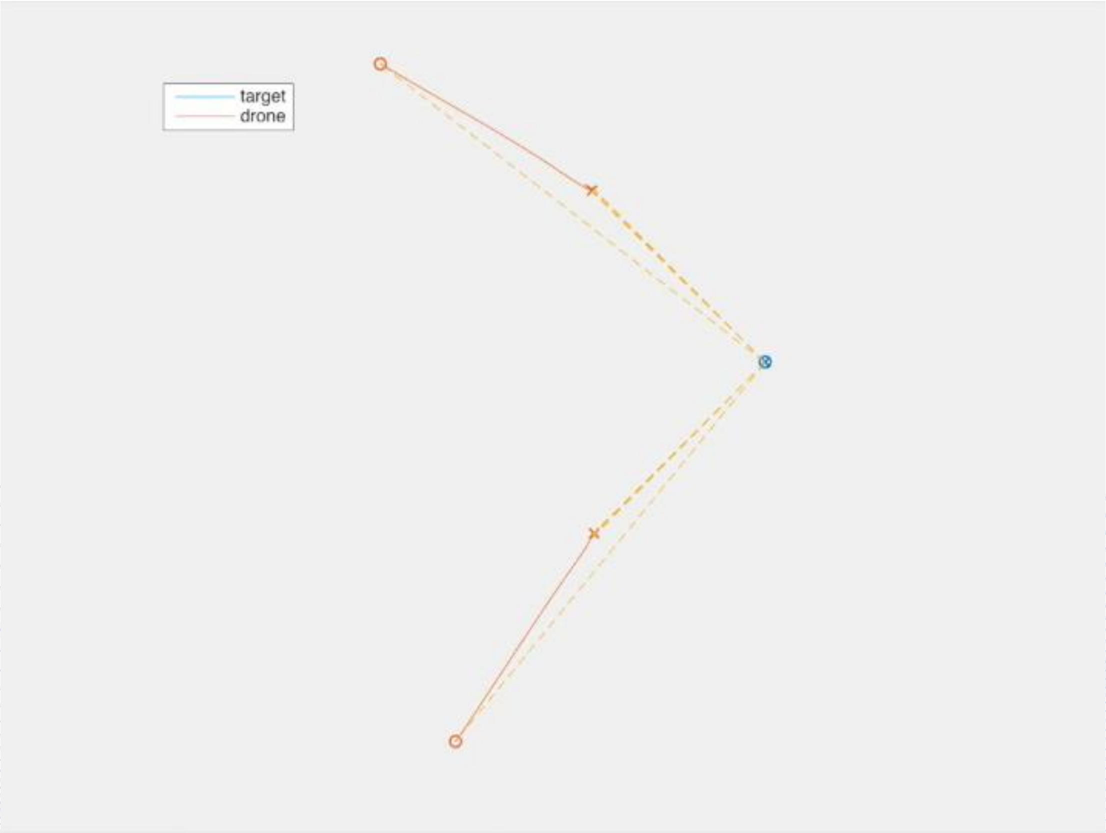


In inertial frame:
Translated identical paths



In trailer frame:
Different paths, no superposition

SA1 - Constant relative positions



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Autonomous System technologies

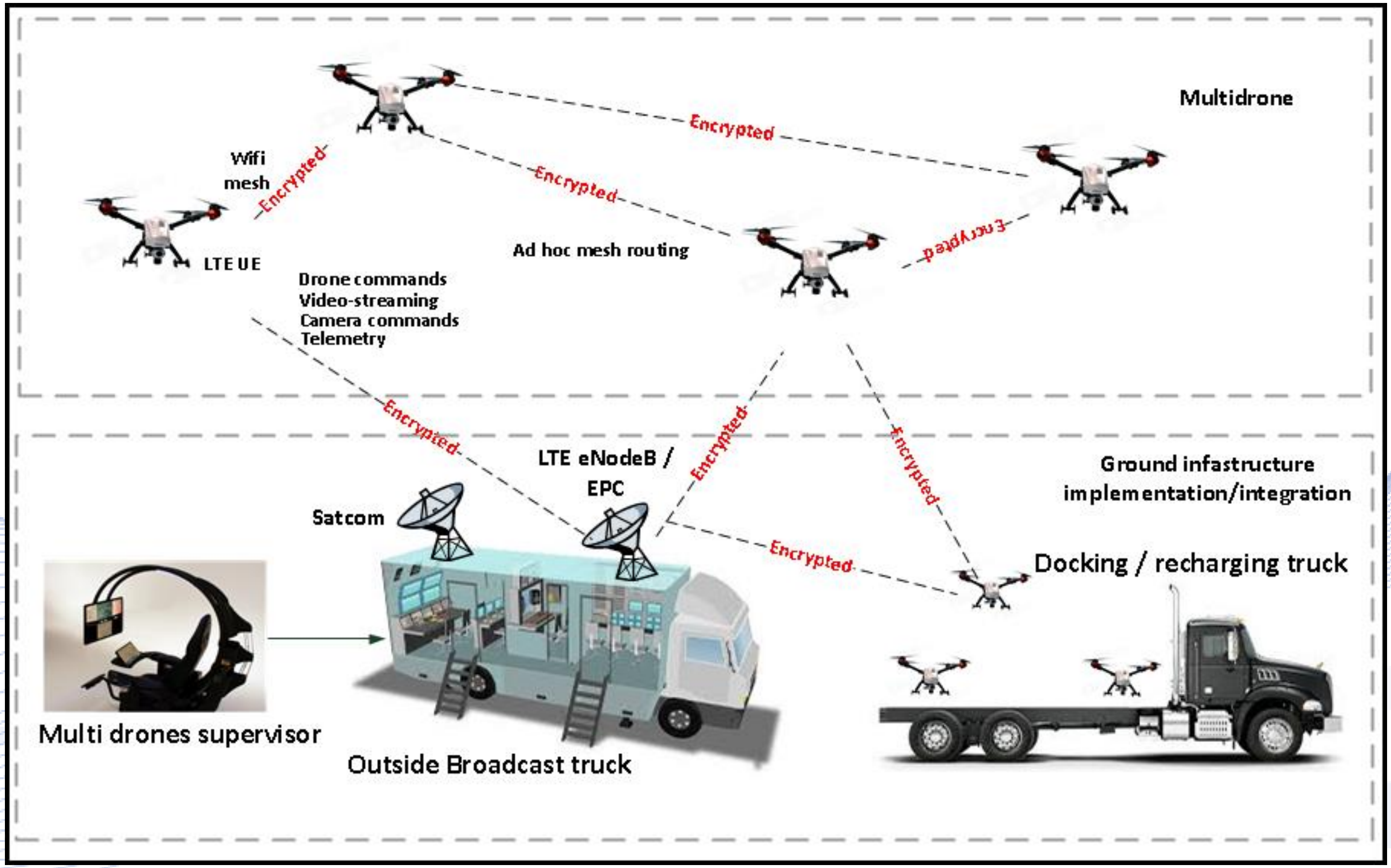
- Mission Planning and Control
- Perception and Intelligence
- Embedded computing
- Swarm systems
- **Communications**
- Societal technologies

Autonomous System Communications

- **Communication infrastructure**
- Video streaming

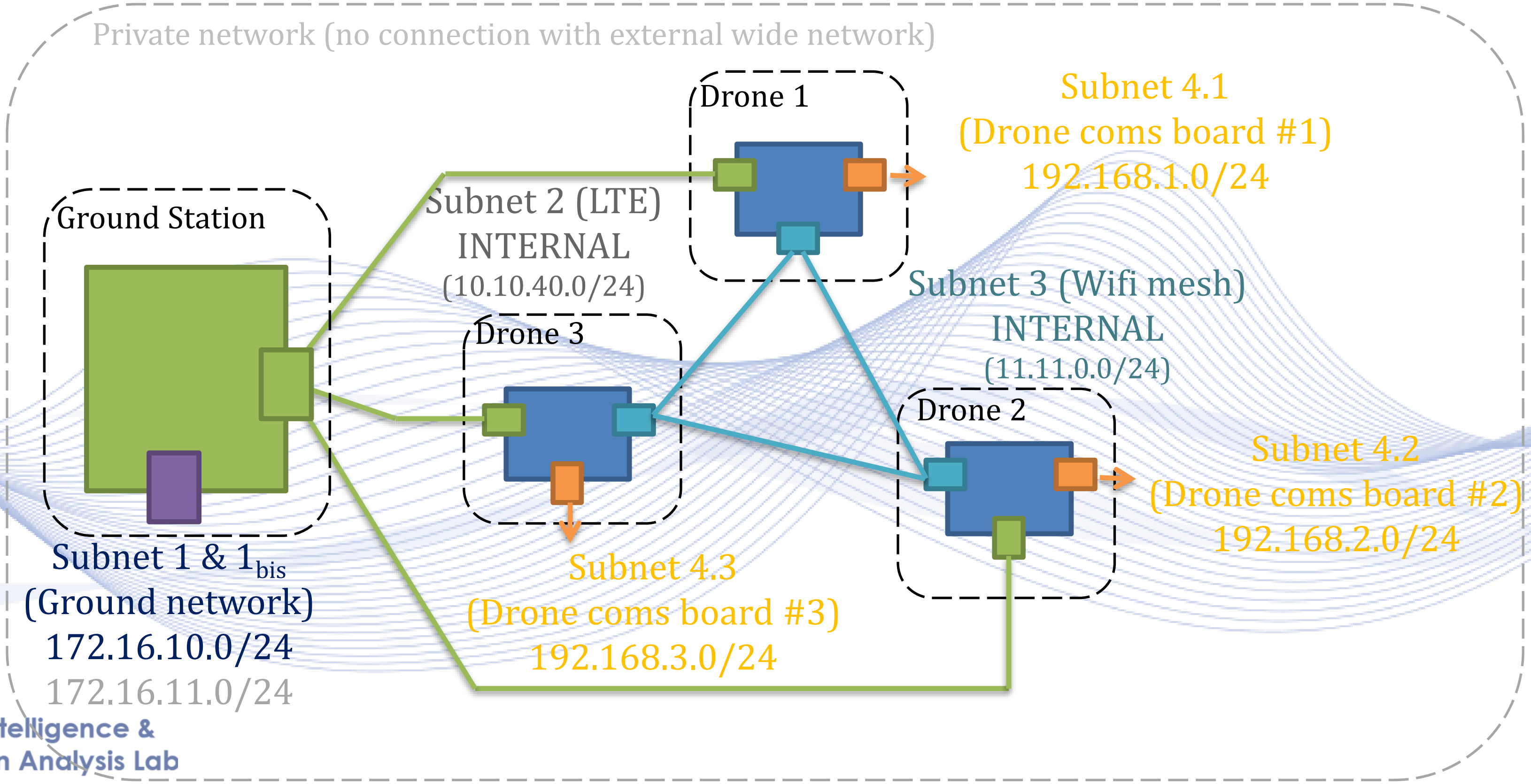
Drone Swarm Communication infrastructure

- Drone2Drone Communication.
- Drone2Ground communication.
- Live broadcasting.



Drone Communications Infrastructure

Objective: Secured and resilient transparent IP access to drones / ground station (LTE and WiFi).



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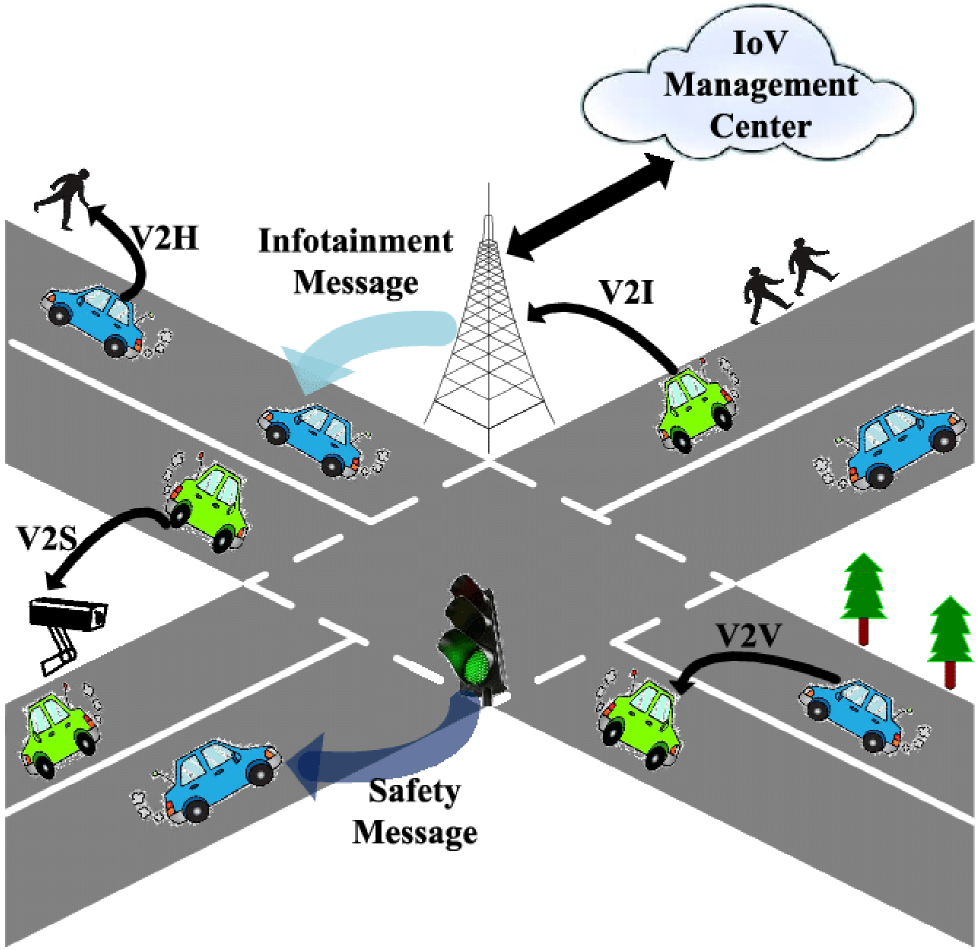
5G Communications Infrastructure

- **Internet of Vehicles**
- Massive deployment, throughput
- Ultra low latency networks
- Robustness
- Edge/cloud computing



Autonomous System Communications

- Communication infrastructure
- **Video streaming**

Drone Digital Video Streaming Problem 1: Network

Considerations:

- **Wireless** communication with receiver - weak & subject to failure (distance, obstacles, other wireless networks etc).
- Good quality video is **massive** in terms of **Mbps** required to transfer it
  - 1 second of 720p (1280x720) **8-bit video** requires 65.92MBytes – prohibitive.
- Video **compression** must be used prior to streaming:
  - H264 & H265 coding are great candidates...
  - ... but they inevitably introduce **delays** (compression + decompression)
  - Lossy: must find **trade-off between latency & quality.**
- Which **network protocol** should be used?
  - Real-time Transport Protocol (**RTP**) with User Datagram Protocol (**UDP**)
  - TCP is also standardized for use with RTP, but favors reliability instead of timeliness.

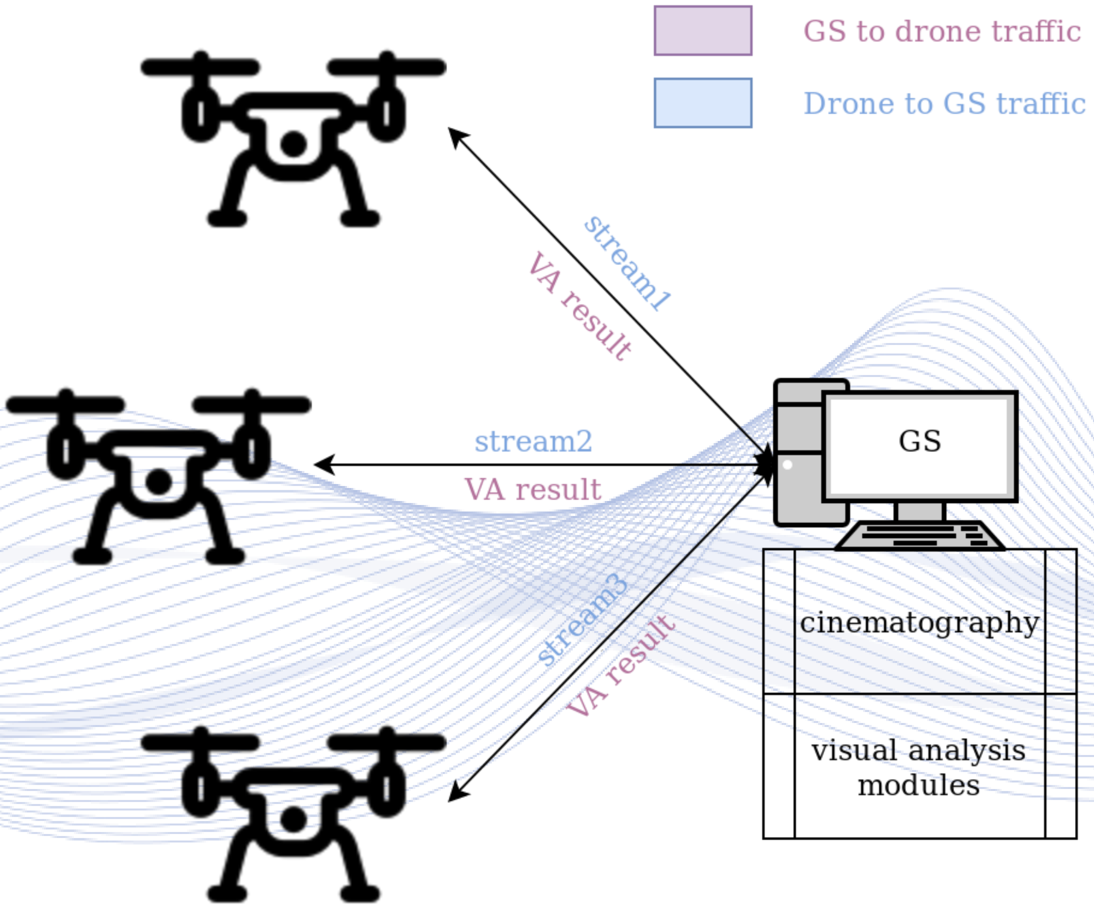
Drone Digital Video Streaming Problem 1: Network

Compression takes place on-board the drone
NVIDIA's Jetson TX2 module offers.

- **hardware accelerated** image/video compression.
  - Also a 256-core Pascal @ 1300MHz GPU with capability comparable to an Intel Xeon E5-2960 v4 CPU in **Deep Learning** tasks.

Drone Digital Video Streaming Problem 2: Synchronization

Scenario 2: multiple drones - one ground station.



Solutions & Tools: Gstreamer

- Gstreamer is written in C, but offers bindings in multiple languages: https://gstreamer.freedesktop.org/bindings/
- Recommended: original C or C++ or Python.
- Sample streamer + receiver are provided in Python:
  - They show how to access pipeline elements & modify them, intercept buffers etc
  - https://lazka.github.io/pgi-docs/#Gst-1.0 python bindings
  - Gstreamer official documentation: https://gstreamer.freedesktop.org/documentation/
  - Useful elements for custom streams: appsrc and appsink.

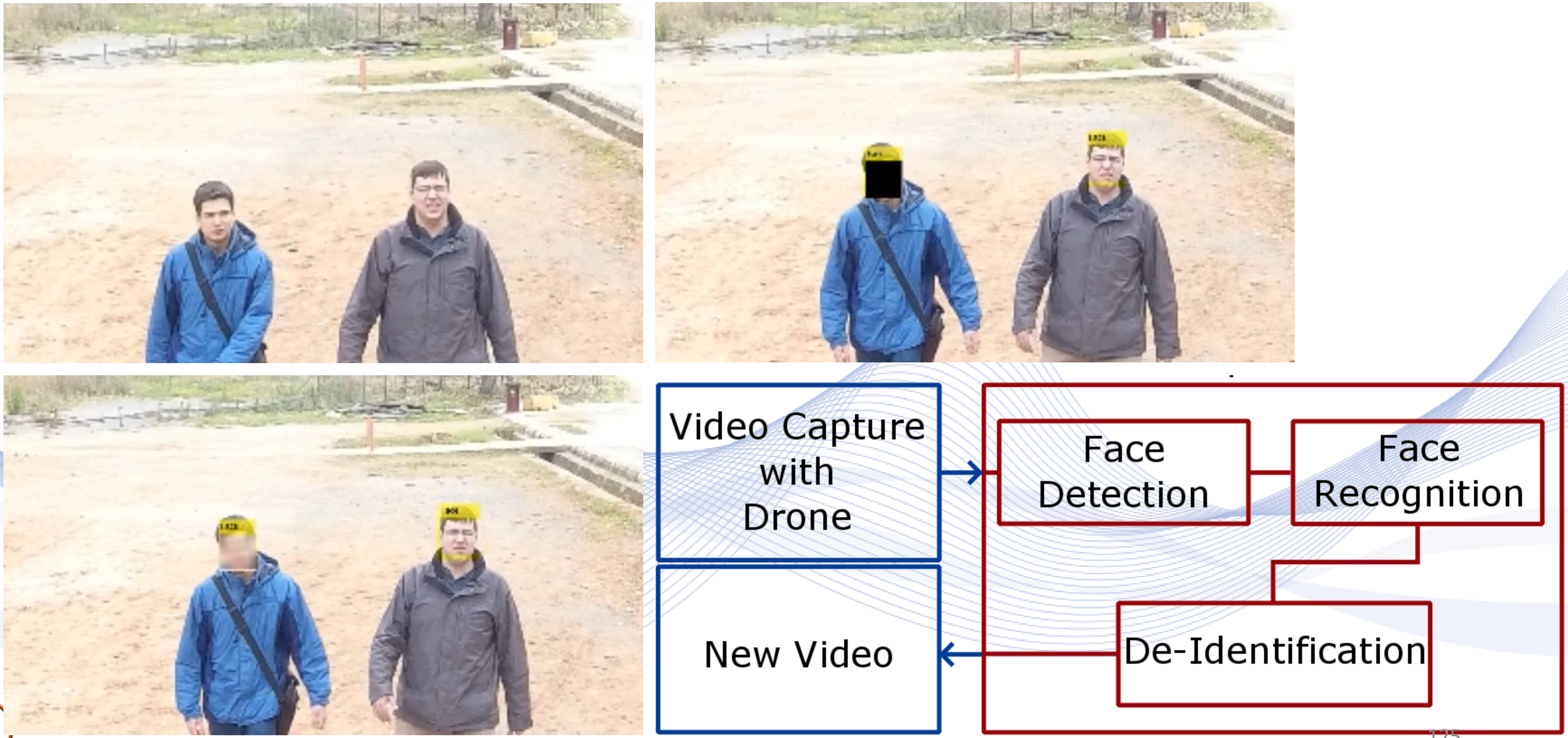
Autonomous System technologies

- Mission Planning and Control
- Perception and Intelligence
- Embedded computing
- Swarm systems
- Communications
- **Societal technologies:**
  - **Security**
  - **Safety**
  - **Privacy protection**

Privacy Protection

- An issue of ethics and security
- Post-production stage
- Approaches
  - Face de-detection (Face detector obfuscation)
    - Naïve approach
    - SVD-DID
  - Face de-identification (face recognizer obfuscation)
    - Gaussian blur
    - Hypersphere projection

Application on drone videos



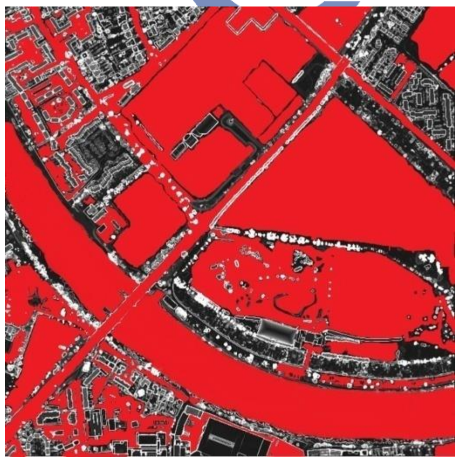
Face recognition/de-identification/privacy protection

UAV flight regulations in EU

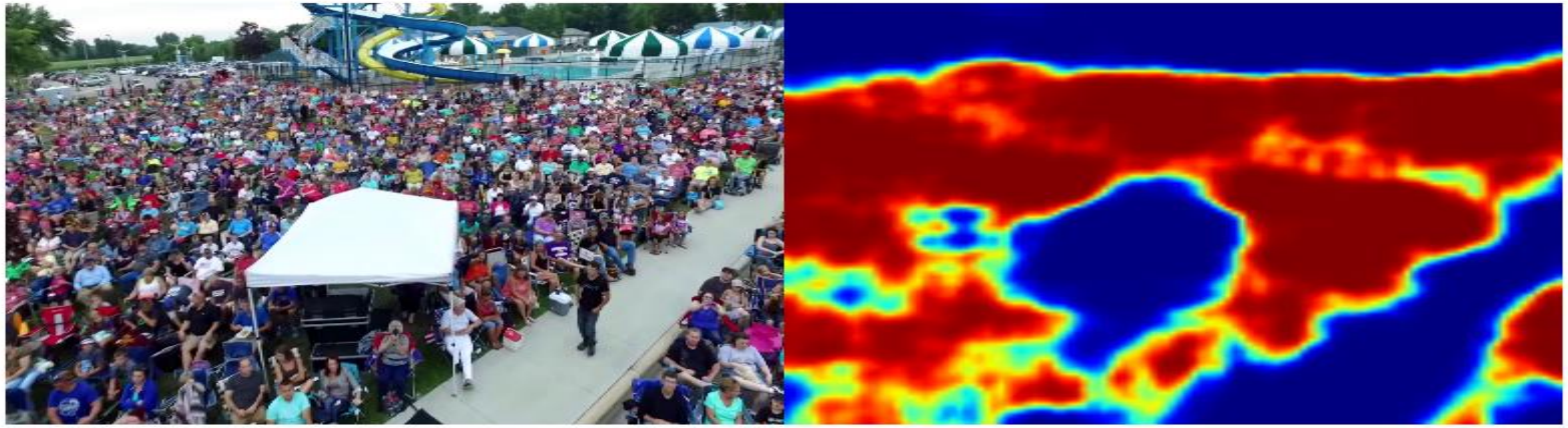
- UAVs < 2kg are allowed within a 50m flight radius without professional pilot license.
- Pilot license and drone insurance are required for all professional applications.
- UAVs > 2kg of weight may be required to carry emergency parachutes (France).
- UAVs exceeding 15kg of weight might require special license or even be prohibited (Germany).

Other UAV safety issues

- Potential Landing Site Detection



- Crowd detection and avoidance



Mission simulations

- Simulations in Gazebo
- Simulations in Unreal Engine and AirSim
- Simulations for training data generation

Pilot Study - Test Content

Object Models

O1 Motorcycles

O2 Sports Car

Background Environment

B1 Down Town

B2 Industrial City

Test Sequence Example II: S2

VIDEO: Scenario 2 with drone height of 1, 2, 6, 10 and 14m.

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Q & A

Thank you very much for your attention!

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