Efficient Swarm Neutralization in Complex Environments using MARL and Adaptive Navigation Strategies

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Decision-making components of autonomous collaborative swarms

Complex adaptive control strategies

Mission phases

Target assignation

Collision avoidance mechanism

Multi-agent Deep RL for Navigation

Heuristics for neutralization

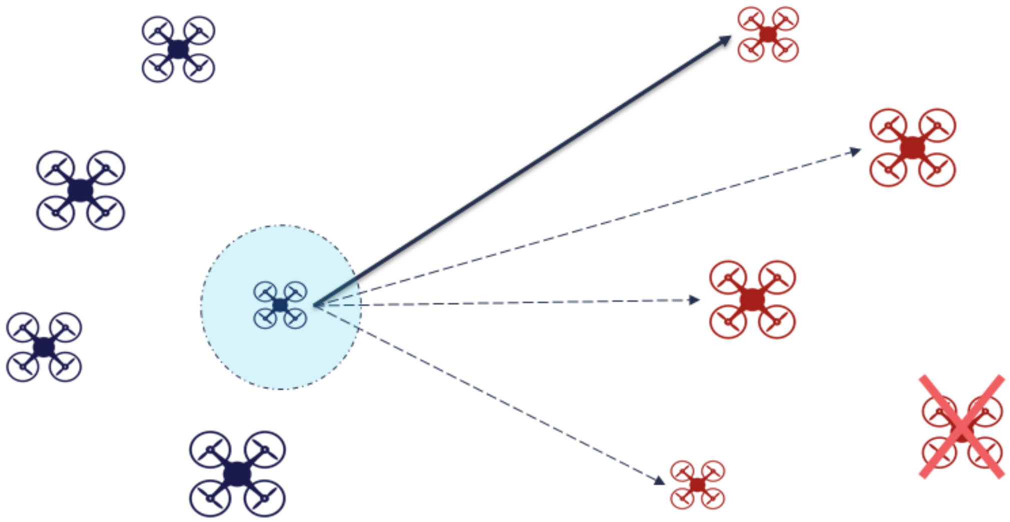
Extra: Visual tracking with autonomous sensing control

Mission Phases to counter-act a intruder swarm

Arming and Take-off	Approaching	Tracking	Catching	Neutralization	Dropping and re-planning
Controlled by the operator	**Deep MARL**	**Deep MARL**	**Rule-based**	**Rule-based**	**Rule-based**
Mission is initiated by the operator. It waits until at least a target is detected to assign autonomously the defending elements to the target(s).	The swarm starts defending autonomously as soon as a target is detected in the "buffer" zone. The goal is to intercept the target(s).	Each agent of the swarm position itself to maintain the tracking of the target(s). An autonomous sensing control helps the visual tracking as well.	When a set of conditions are met, one selected UAV navigates with a catching strategy to a selected target.	The neutralization occurs when the position of the target and captor met. In our case, the neutralization payload used in simulations is a net.	The captured target is retrieved to a safe area. After, the drone can re-plan for tracking purposes.

Target Assignation Algorithm

> Challenge: Assign N defending drones to M targets, where M <= N



> Algorithm: Minimum collaborative distance

$$f = \sum_{i=1}^{N} \sum_{j=1}^{M} d_{ij} \cdot x_{ij}$$

Conditions:

$$\sum_{i=1}^{N} x_{ij} \geq 1$$

A target must be have at least on defending drone assigned to it

$$\sum_{j=1}^{M} x_{ij} = 1$$

A defending drone must have only one target assigned

Limitations: $ON!$

Deep MARL for navigation

> Challenge: Collaborative swarm behaviour for navigation

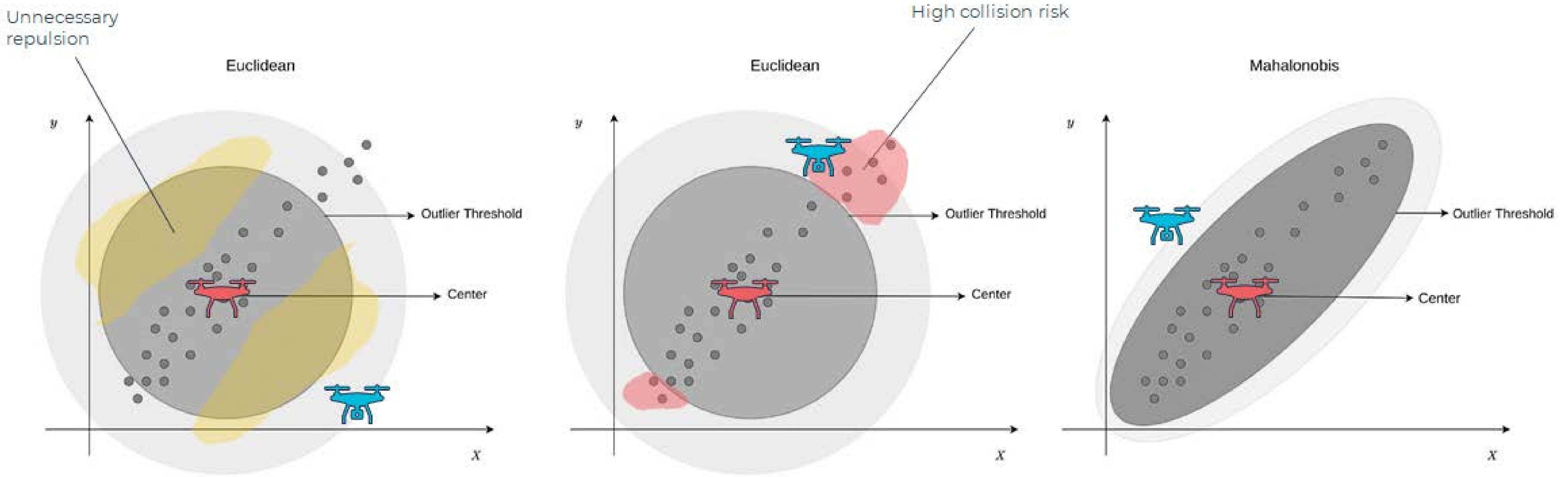
> Algorithm: Off-policy multi-agent Deep Reinforcement Learning

- **Off policy:** To be sample efficient
- **Centralized training and decentralized execution:** To be independent but collaborative
- **Reinforcement Learning:** Best strategy is learnt

*2D example, actual training was conducted in a 3D simulator

Dynamic adaptive local fields for collision avoidance

> Challenge: Non-stationary position uncertainty on a 3D volume



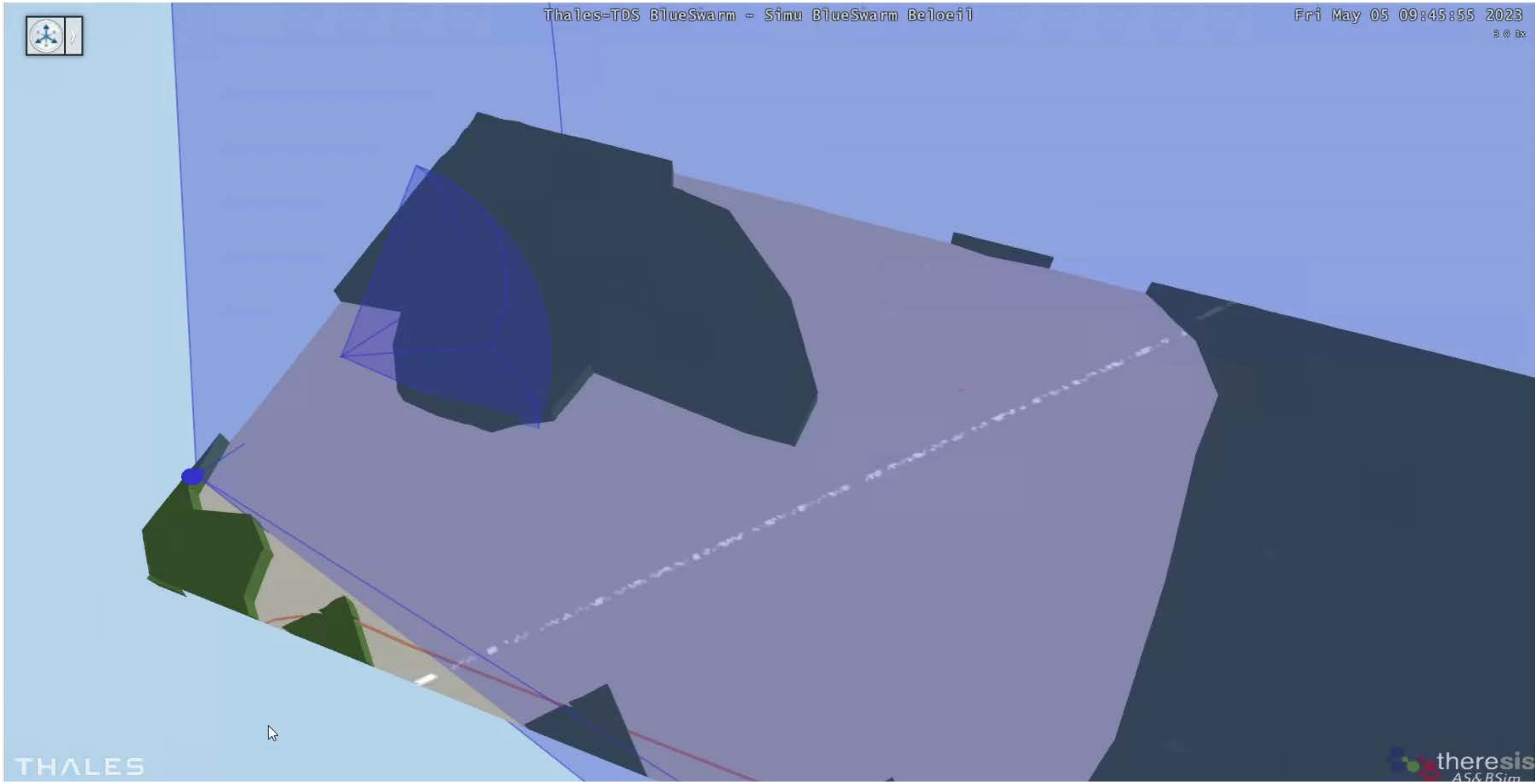
Possible entity positions at time t (previous)

Safety zone in dark gray, the volume is fixed during the whole mission

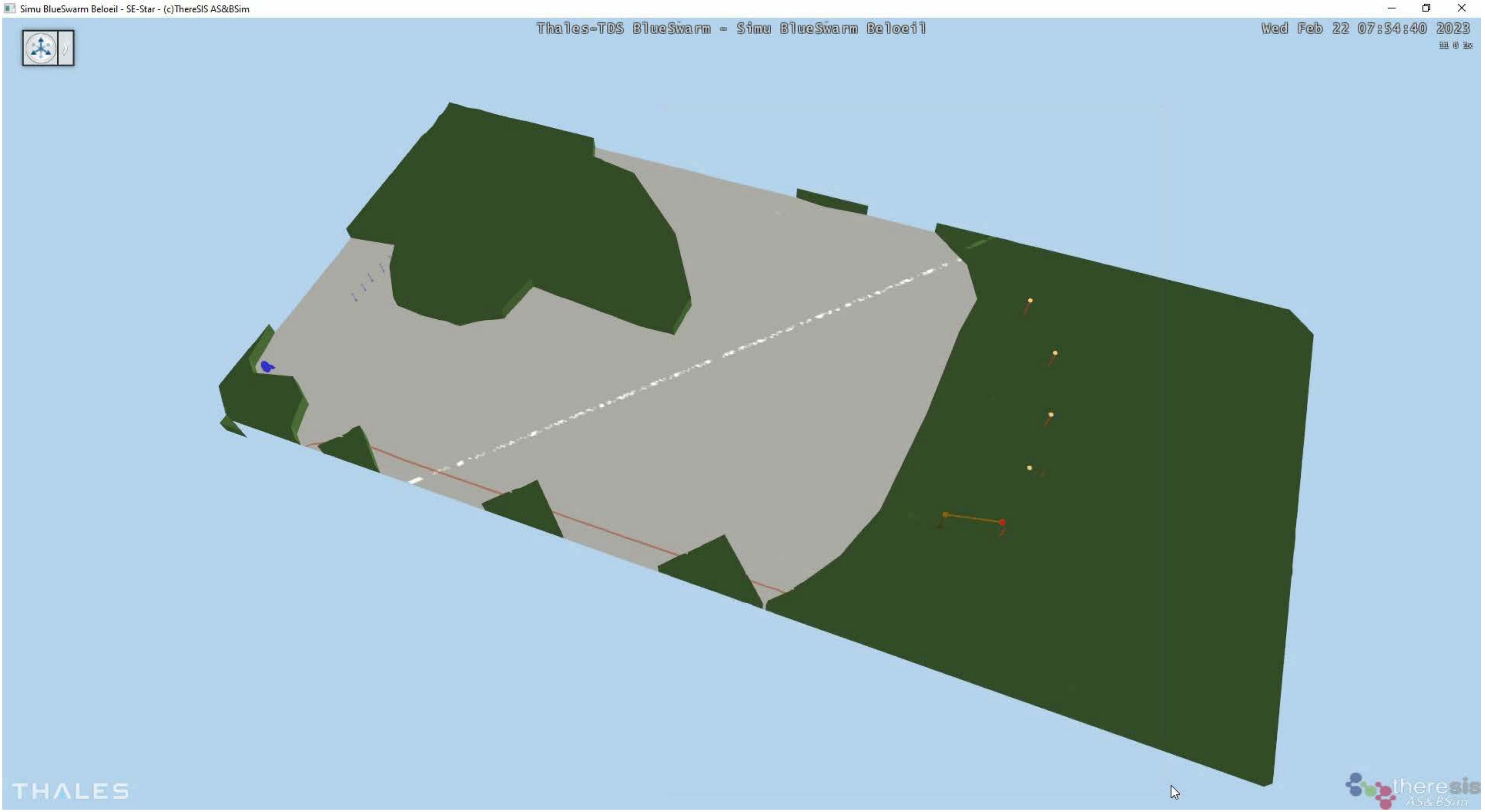
Possible entity positions at time t (new)

Safety zone in dark gray is computed **at each time step**

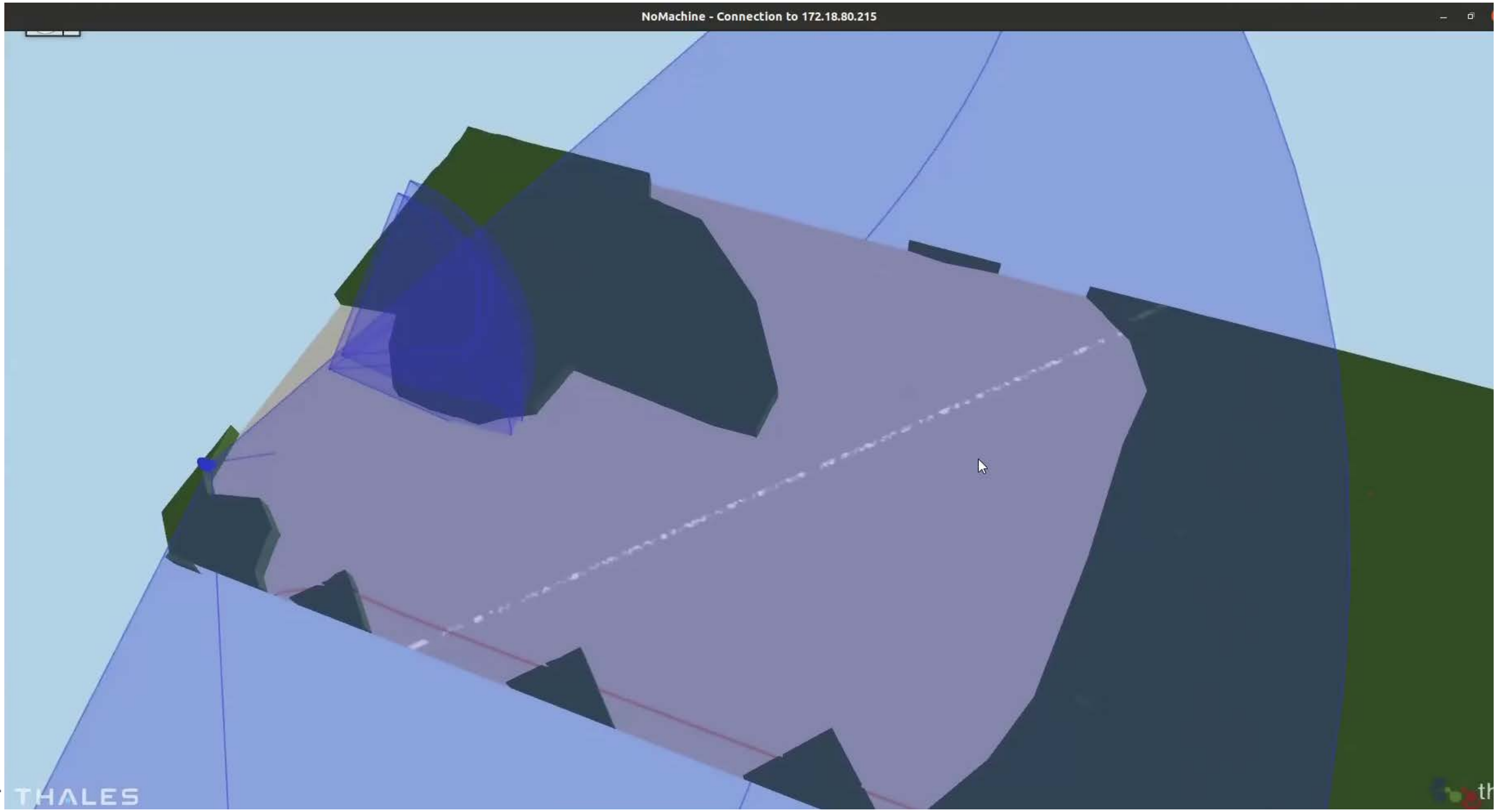
Tracking (including sensing control) with collision avoidance



Neutralizing an enemy swarm (5 vs 5)



Neutralizing an enemy: Close-up on payload control and replanning



Sensing control: Pan, tilt and zoom

> **Challenge: Capture a target visually using autonomous sensing control on a moving defending drone with a EO camera**









Note that the “buffer zone” is a volume of approximately **600m x 400m 70m**, and the size of a drone is near **1m x 1m x 0.5m**

Process slide

1

Conclusion

- A safe and performant set of interdependent algorithms for tracking and neutralizing a swarm of UAVs.
- Combination of Machine Learning and Rule-based algorithms through the notion of Mission Phases.
- Successfully tested on simulations and in real flight demonstrations

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Limitations

- Weather conditions and actual dynamics for training
- Radar performance and uncertainty (situational awareness in general)
- Target assignation algorithm increases exponentially with a higher number of drones
- Generalization might be limited for some use cases

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Future work

- Human-in-the-loop
- Better situational awareness
- Improve stability for visual tracking
- Enhance safety by decreasing the risk of collisions
- Increase the maturity of the solution in general

Questions?

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