AI-Based Attacker-Defender Game of Autonomous Vehicle Teams

Thrust Area 5: Vehicle System Integration, Optimization, and Robustness

Quad Members: Yanchao Tan\textsuperscript{SM}, Chengfeng Xu\textsuperscript{SM}, Bogdan Epureanu (PI), Panos Papalambros (co-PI), Matthew Castanie\textsuperscript{US ARMY GVSC}, Richard Gerth\textsuperscript{AC GVSC}, Ra’ed Seifeldin\textsuperscript{ONR}, Xingyu Li\textsuperscript{Ford}, Mainak Mitra\textsuperscript{Ansys}, Edward Umpfenbach\textsuperscript{GM}

Motivation

- Fleet modularity promises significant benefits in terms of reduced acquisition cost and enhanced flexibility in fleet operation
- Flexibility in operation also raises the complexity in fleet operation, i.e., vehicle assembly, disassembly, and reconfiguration

Fundamental Research Questions

- How to create a vehicle-level agent-based model for fleet operations which handles a large number of agents, reacts to stochasticity in the environment and in adversarial actions, and overcomes geographical and communication constraints?

Approach

Two approaches have been investigated:

- Discrete space model: use the Dijkstra’s algorithm for path planning with geographical and communication constraints
- Continuous space model: use model predictive control to plan the motion of adversarial vehicle teams

Collaborative Navigation: Graph-Based Model

- States: physical vehicle location, and knowledge of edge weights
- Collaboration: edge weights are updated by new observations and by communication among teammates

- Navigation: Dijkstra’s algorithm used to minimize the cost of traveled edges from a start node $n_s$ to an end node $n_d$

$$
\text{Min } J = \sum_i C_{e_i}, \quad \text{s.t. } \sum e_i + n_e = n_d
$$

Multiple-Attackers-Multiple-Defenders Game: MPC-Based Model

- Objectives of the defender:
  - Minimize the weighted distance to demands
  - Maximize the weighted distance to attackers

$$
\text{Min } J = \sum_{i=t_0+1}^{t_F} \sum_k w_k \left[x_{d_i}(t) - x_{a_k}(t)\right]^2 - \sum_j w_j \left[x_{d_j}(t) - x_{a_j}(t)\right]^2
$$

- Objective of the attacker:
  - Minimize weighted distance to defenders

$$
\text{Min } J = \sum_{i=t_0+1}^{t_F} \sum_j w_j \left[x_{d_i}(t) - x_{a_j}(t)\right]^2
$$

Objectives

- Model the behavior of fleet systems composed of teams of modular vehicles with human-operated and autonomous modules
- Determine possible ways to improve the overall system dynamics in terms of collaboration, negotiation, and competition
- Evaluate fleet performance with optimized communication strategy given the AI-based decision-making strategy of all entities

Results and Conclusion

Performance with & without communication

- Each vehicle can only observe a 30x30 area of the map
- Each vehicle shares all observations with teammates once communication is allowed

Examples of different vehicle behaviors

- Assume that vehicles always know the adversarial path
- Demand changes from Demand 1 to Demand 2 at time index 50

Demand-Oriented Defender  Risk-Averse Defender

- Communication raises the average amount of resources collected

Future Work

- Use deep reinforcement learning to select communication strategies based on situational awareness (knowledge)
- Implement predictive modeling for each team to forecast the adversarial behavior (path) in near future

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