Université Claude Bernard Lyon 1

ENERGY AND INDUSTRY OF THE FUTURE

Design, Learning, and Experimental Validation of Safe Pursuit-Evasion Strategies for Multi-Agent Autonomous Robots

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Master 2 : Master Automatique Robotique
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Abstract:
Pursuit–evasion games provide a stimulating framework for studying decision-making, control, and interaction among autonomous agents. They involve pursuers and evaders evolving in complex environments where speed, safety, and adaptability are critical. These problems have direct applications in mobile robotics, autonomous navigation, security, and multi-robot cooperation. The objective of this project is to design and evaluate control and learning strategies for autonomous agents engaged in pursuit–evasion scenarios.
Three main directions will be explored: (1) dynamic modeling of the agents, (2) implementation of predictive control strategies (MPC) and safety-critical Control Barrier Functions (CBFs), and (3) integration of reinforcement learning (RL) approaches to enable adaptation in uncertain environments.
The methods will first be developed and benchmarked in simulation (Python, MATLAB/Simulink), then validated in a ROS2/Gazebo environment, with possible experiments on TurtleBot platforms.

Project description:
Pursuit–evasion games (PEGs) constitute a reference framework for investigating optimal decision-making, control, and coordination among autonomous agents. They involve dynamic interactions between one or several pursuers and evaders evolving within constrained environments. Such scenarios lie at the core of various applications, including security and surveillance, mobile robotics, cooperative exploration, and autonomous navigation.
PEGs combine several major challenges:

- Multi-agent dynamic modeling with explicit consideration of uncertainties.
- Convergence and computational complexity of optimal control solutions.
- Safety guarantees through Control Barrier Functions (CBFs) or Model Predictive Control (MPC).
- Adaptive learning in uncertain environments using Reinforcement Learning (RL) or Multi-Agent RL.

Despite recent progress (Wang et al., 2025; Hu et al., 2025; Sani, Robu, Hably, 2020), no “off-the-shelf” solution yet provides simultaneous safety, adaptability, and real-time feasibility in practical robotic settings.

The project therefore aims to:

- Model the agents' dynamics and constraints (differential kinematics, actuation limits, sensor noise, ROS2 latency).
- Design simple heuristic control laws (proportional pursuit, geometric evasion strategies) to establish baseline performance.
- Implement advanced control strategies:
  - Model Predictive Control (MPC) for horizon-based planning.
  - Control Barrier Functions (CBFs) for safety (collision avoidance, forbidden-zone enforcement). These methods raise numerical-convergence and computational-complexity challenges that will be analyzed.
- Introduce Reinforcement Learning (RL) to adapt strategies to disturbances or non-stationary adversaries.
- Develop a hybrid MPC/CBF–RL framework: MPC ensures safety while RL refines decision-making under uncertainty.
- Experimentally validate the strategies on TurtleBot robots using ROS2/Gazebo, with potential real-world tests.

Candidate Profile

This internship is open to motivated students with a solid background in control, robotics, or applied mathematics. Candidates should have strong analytical skills and be comfortable with simulation tools (Python, MATLAB/Simulink) and basic robotic frameworks. Interest in MPC, safety-critical control, or reinforcement learning is highly valued.

We seek a rigorous, curious student eager to engage in both theoretical work and practical experiments on autonomous robotic systems.

[1] Y. Wang, H. Zhang, J. Xu, S. Wang & M. Guay. *Reinforcement learning in pursuit-evasion differential game: safety, stability and robustness.* arXiv preprint, 2025.

[2] N. Chen, L. Li & W. Mao. *Equilibrium strategy of the pursuit-evasion game in three-dimensional space.* IEEE/CAA Journal of Automatica Sinica, vol. 11, no. 2, pp. 446-458, Feb. 2024.

[3] J. Selvakumar & E. Bakolas. *Min–Max Q-learning for multi-player pursuit-evasion games.* Neurocomputing, 2022.

[4] H. Xiong, H. Cao, L. Zhang & W. Lu. *A Dynamics Perspective of Pursuit-Evasion Games of Intelligent Agents with the Ability to Learn.* arXiv, Apr. 2021.

[5] Z. Zhou & H. Xu. *Mean Field Game and Decentralized Intelligent Adaptive Pursuit-Evasion Strategy for Massive Multi-Agent System under Uncertain Environment.* arXiv, 2020.

[6] M. Sani, B. Robu & A. Hably. *Pursuit-evasion Game for Nonholonomic Mobile Robots With Obstacle Avoidance using NMPC.* MED 2020 (28th Mediterranean Conference on Control and Automation), Sep. 2020.

[7] P. Hu, C. Zhao & Q. Pan. *A Novel Method for a Pursuit–Evasion Game Based on Fuzzy Q-Learning and Model-Predictive Control.* Drones, 2024, 8(9):509.

[8] A. J. Badakaya, A. S. Halliru & J. Adamu. *A differential game of pursuit-evasion with constrained players' energy.* Data Analytics and Applied Mathematics, vol. v3, i1, 2022.