Robust signal temporal logic model predictive control

Stage Master 2, 2023–2024

Key words : Robust Model Predictive Control
Signal Temporal Logic Specification
Mixed-Integer Linear Programming

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Duration: 6 months

Scholarship: according to the legislation in force

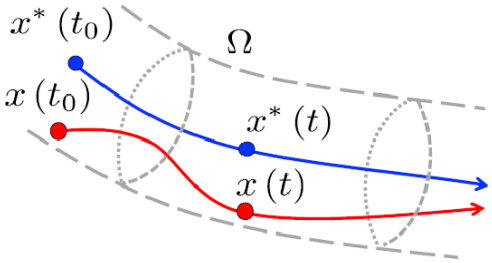
Context Temporal logic allows to reason about systems' temporal properties and has traditionally been used in formal verification and model checking. More recently, they were adapted to specify complex behavior for autonomous systems, raising the wave of research in designing control strategies ensuring the closed-loop system satisfies the requirements.

During the internship, we propose to focus on specifications given by signal temporal logic formulas. First, since the language described by STL is quite rich. For example, using STL formalization, we can give the following task to a drone filming the area:

> Iteratively go from point A to point B and back. Always avoid obstacles while moving. If your battery is out of charge in the next 30 minutes, go to charging point C and charge completely.

Second, STL formulas also have the advantage of naturally admitting quantitative semantics, which, in addition to the binary answer to the question of satisfaction, provides a real number indicating the quality of the satisfaction or violation.

For deterministic linear discrete-time systems, it was proposed in [4] to transform the STL specification (with linear predicates) into mixed-integer linear constraints. The authors then used Model Predictive Control (MPC) to generate (sub)optimal (w.r.t. the quality of the formulas' satisfaction) control strategies for the system with these constraints. The nested mixed-integer linear programming problem is tackled by a modern solver.



However, the proposed approach has limitations: the state of the plant is supposed to be fully observable, and the environmental inputs are known in advance. We aim to overcome these limitations using tube-based model predictive control [2, 3], which is robust to bounded disturbances. In tube-based MPC, an ancillary feedback controller is designed to keep the actual state within an invariant "tube" around a nominal trajectory computed, neglecting disturbances. For a given STL formula, let us synthesize the reference controller using the approach from [4]. Then, the reference trajectory satisfies the specification. However, there is no guarantee that other trajectories from the tube do... If you are interested in resolving this issue, don't hesitate to apply for this internship.

The goals of the internship. The goals of the internship consist of

- exploring state of the art, which includes:
  - signal temporal logic specifications and its quantitative semantics;
  - robust model predictive control approaches.
  - existing solvers for a mixed-integer linear programming problem.
- designing a controller for a signal temporal logical specification robust to additive disturbance.
- implementing the designed controller for a Tello drone.

Profile of a candidate. For this position, you should meet the following requirements:

- enrollment in a Master's program or equivalent in computer science, applied mathematics science, engineering, or related disciplines;
- rigorous knowledge in optimization, numerical calculus, and systems control;
- excellent programming skills (C++, Python);
- proficiency in spoken and written English;

The candidate will have to submit by email the documents following:

- a cover letter;
- a resume;
- a copy of diplomas and bachelor's degree transcripts and Master.

References

[1] J. Alexandre dit Sandretto. Reliable nonlinear model-predictive control via validated simulation. In *2018 Annual American Control Conference (ACC)*, pages 609–614, 2018.

[2] W. Langson, I. Chryssochoos, S. Raković, and D. Mayne. Robust model predictive control using tubes. *Automatica*, 40(1):125–133, 2004.

[3] D. Limon, I. Alvarado, T. Alamo, and E. Camacho. Robust tube-based mpc for tracking of constrained linear systems with additive disturbances. *Journal of Process Control*, 20(3):248–260, 2010.

[4] V. Raman, A. Donzé, M. Maasoumy, R. M. Murray, A. Sangiovanni-Vincentelli, and S. A. Seshia. Model predictive control with signal temporal logic specifications. In *53rd IEEE Conference on Decision and Control*, pages 81–87. IEEE, 2014.