Study of Signal Temporal Logic Robustness Metrics for Optimization-based Trajectory Repairing

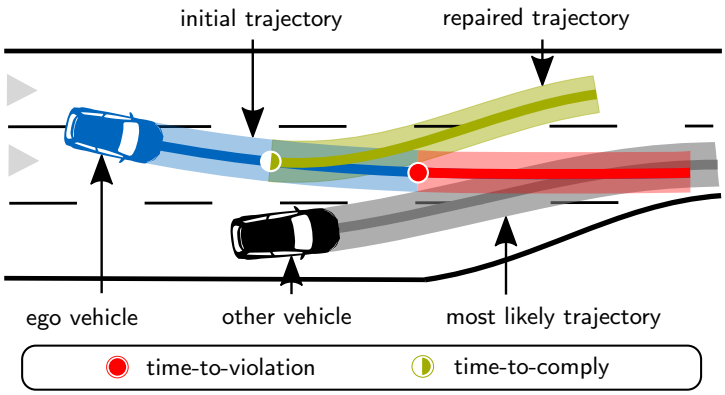
Background

Autonomous vehicles need to comply with traffic rules so that they cannot be held liable for traffic accidents. To formalize the traffic rules in a precise and machine-readable manner, temporal logic languages are often used. Linear temporal logic (LTL) [1, 2] and metric temporal logic (MTL) [3] provide Boolean values for traffic rule satisfaction or violation. To better evaluate continuous dynamics, signal temporal logic (STL) [4] extends the MTL to specify real-valued solutions with the quantitative *robustness degree* [5], which indicates how far is a signal from satisfying a specification.

If planned trajectories are not rule-compliant or physically infeasible, one can replan them for consecutive planning cycles. However, replanning a complete trajectory is often unnecessary and time-consuming. To solve this challenge, one interesting approach is trajectory repairing proposed in our previous work [6].

Description

Trajectory repairing with respect to complex specifications is computationally challenging due to the coupling of dynamical feasibility requirements and high-level specifications. In our previous work, we use convex optimization technologies as well as stochastic-optimization-based approaches to model the rule-compliant trajectory repairing problem. Both are based on CommonRoad[1] [7], which is a collection of composable benchmarks for motion planning on roads. However, if we use the latter approach, the robustness degree of multiple traffic rule formulae is nonconvex and nondifferentiable in the initial definition. To address the above issues of robustness, several alternative definitions have been proposed in recent years: arithmetic geometric mean (AGM) robustness [8], smooth robustness [9], and new robustness [10], which are summarized in [11].



Sketch of trajectory repairing regarding traffic rule violations. The initially-planned trajectory for the ego vehicle violates the traffic rule since it does not yield to vehicles entering the main carriageway from the access ramp [3].

Tasks

- Literature review of works related to signal temporal logic and its quantitative metrics, i.e., robustness degree [5]
- Familiarizing with the current robustness function definition in [12] and the existing traffic rule monitor as well as the optimization-based trajectory-repairing framework in CommonRoad platform

[1] https://commonroad.in.tum.de/

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Research project:
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Type:
BA/SA/MA

Research area:
Motion Planning, Traffic Rules, Temporal Logic

Programming language:
Python

Required skills:
Advanced programming skill, able to work independently, familiar with logic

Language:
English

Date of submission:
24. Februar 2022

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- Implementing benchmarks for evaluating different metrics
- Implementing and comparing different robustness metrics
- Evaluation of the metrics on CommonRoad scenarios in the trajectory-repairing framework
- Documentation of codes and other related materials

References

[1] A. Rizaldi, F. Immler, B. Schürmann, and M. Althoff, "A formally verified motion planner for autonomous vehicles," in *Proc. of the Int. Symposium on Automated Technology for Verification and Analysis*, pp. 75–90, 2018.

[2] K. Esterle, L. Gressenbuch, and A. Knoll, "Formalizing traffic rules for machine interpretability," in *Proc. of the IEEE Connected and Automated Vehicles Symposium*, pp. 1–7, 2020.

[3] S. Maierhofer, A.-K. Rettinger, E. C. Mayer, and M. Althoff, "Formalization of interstate traffic rules in temporal logic," in *Proc. of the IEEE Intelligent Vehicles Symposium*, pp. 752–759, 2020.

[4] L. Gressenbuch and M. Althoff, "Predictive monitoring of traffic rules," in *Proc. of the IEEE Int. Intelligent Transportation Systems Conf.*, IEEE, 2021.

[5] G. E. Fainekos and G. J. Pappas, "Robustness of temporal logic specifications for continuous-time signals," *Theoretical Computer Science*, vol. 410, no. 42, pp. 4262–4291, 2009.

[6] Y. Lin, S. Maierhofer, and M. Althoff, "Sampling-based trajectory repairing for autonomous vehicles," in *2021 IEEE International Conference on Intelligent Transportation Systems (ITSC)*, pp. 572–579, 2021.

[7] M. Althoff, M. Koschi, and S. Manzinger, "CommonRoad: Composable benchmarks for motion planning on roads," in *Proc. of the IEEE Intelligent Vehicles Symposium*, pp. 719–726, 2017.

[8] N. Mehdipour, C. I. Vasile, and C. Belta, "Arithmetic-geometric mean robustness for control from signal temporal logic specifications," *Proceedings of the American Control Conference*, vol. 2019-July, pp. 1690–1695, 2019.

[9] Y. Gilpin, V. Kurtz, and H. Lin, "A Smooth Robustness Measure of Signal Temporal Logic for Symbolic Control," *IEEE Control Systems Letters*, vol. 5, no. 1, pp. 241–246, 2021.

[10] P. Varnai and D. V. Dimarogonas, "On Robustness Metrics for Learning STL Tasks," *Proceedings of the American Control Conference*, vol. 2020-July, pp. 5394–5399, 2020.

[11] A. Dhonthi, P. Schillinger, L. Rozo, and D. Nardi, "Study of Signal Temporal Logic Robustness Metrics for Robotic Tasks Optimization," *Iros-Ws*, pp. 2–4, 2021.

[12] L. Gressenbuch and M. Althoff, "Predictive monitoring of traffic rules," in *Proc. of the IEEE Int. Conf. on Intelligent Transportation Systems*, 2021.

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