Learning-based vs. Fail-Safe Collision Checks for Air- and Spacecrafts

Background

When checking whether an air- or spacecraft trajectory is safe, one has to check that the trajectory in question does not hit a dangerous object, such as another aircraft, a satellite, or any other object that may interfere with the planned flight path. To that end, a common strategy is to model the vehicle and the (dangerous) object as sets, compute the trajectory of such sets, and then check for a given point in time whether the two sets intersect. If the dangerous object is significantly smaller than the vehicle (e.g., a bird or a meteorite), it suffices to check whether the object lies inside the trajectory of the vehicle.

These kind of problems are called containment problems. Although they can not always be solved algorithmically, they are often solvable for most usual set representations, e.g., polytopes, zonotopes, ellipsoids, ...

More generally, containment problems are used for reachability analysis, set-based observers, fault detection, robust control, controller synthesis, and conformance checking. Currently, containment checks are performed mostly on zonotopes or polytopes, as they are convex and can thus easily represent an autonomous car or a robot arm. However, air- and spacecrafts may be non-convex due to their wings, and thus other set representations need to be used, for example polynomial zonotopes [1]. Due to the non-convexity of such set representations, many properties that were easy to check for zonotopes or polytopes become more intricate and difficult.

This is also the case for containment problems, and one way to remedy this issue is to split a polynomial zonotope, over-approximate each part with a zonotope, and then check containment. Due to this over-approximation, significant errors can be made, and it is therefore of interest whether a better method can be found.

Description

By simulating the scenario of a small meteorite passing next to a spaceship (modeled using a polynomial zonotope), the goal is to check whether the meteorite will collide with the spacecraft or not. Two very different methods are available: The first method uses optimization solvers based on learning algorithms that can guess rapidly whether the meteorite will hit the spacecraft. The second method computes the exact answer using geometric properties, but can take (much, much) longer to compute. The focus of this thesis is therefore to implement and compare both approaches.

Tasks

- Literature review on the topic of containment problems and learning-based optimization solvers
- Implementation of a learning-based algorithm and/or an exact geometric algorithm
- Evaluation of the performance by comparing the results to the currently implemented method in CORA
- Integration of the final implementation into the CORA toolbox
- Testing the implementation on a functional air- or spacecraft model

References

[1] Niklas Kochdumper and Matthias Althoff. Constrained polynomial zonotopes, 2020.

[2] A. Kulmburg and M. Althoff. On the co-np-completeness of the zonotope containment problem. *European Journal of Control*, To appear.

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