A penalty method algorithm for obstacle avoidance using nonlinear model predictive control

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1 Introduction

Applications of autonomous motion systems are arising more and more in industry. Examples are driverless cars, fruit-picking robots and automated guided vehicles in an automated warehouse. Computation of a collision free trajectory is essential in such applications. Various techniques to compute motion trajectories that satisfy collision-avoidance constraints have been proposed, including graph-search methods, virtual potential field methods and methods using the concept of velocity obstacles. Recently, optimization-based strategies are becoming more popular. In such strategies, the search for a time, energy... optimal trajectory is formulated as an optimization problem. In order to take into account disturbances and uncertainty in the environment, this optimization problem needs to be solved in real time.

This abstract presents a penalty method algorithm to calculate a trajectory while satisfying collision-avoidance constraints. Through the introduction of penalty parameters, a trade-off is possible between the optimality of the trajectory and the extent to which the obstacle constraints are violated. The resulting optimization problems are solved using a proximal averaged Newton-type method for optimal control (PANOC), as proposed in [1]. In addition, some heuristics are developed for dealing with local optima when the obstacles are non-convex.

2 Methodology

The trajectory computation is formulated as an optimal control problem. Nonlinear vehicle dynamics can be accounted for, and the problem is transformed into a small-scale nonlinear program using single shooting. Box constraints on the inputs can directly be accounted for by PANOC, whereas state constraints can only be included through a penalty. Hence, for our application, the objective of the control problem comprises two parts: a least squares objective in terms of the states and inputs, and a penalty that represents the violation of the obstacle boundaries. This second term is directly related to our formulation of an obstacle as the intersection of a finite number of m strict nonlinear inequalities:

$$O = \{z \in \mathbb{R}^{n_d} : h_i(z) > 0, i \in \mathbb{N}_{[1,m]}\}.$$

The obstacle avoidance constraint can then be written as:

$$\psi_O(z) := \frac{1}{2}\prod_{i=1}^{m}[h_i(z)]_+^2 = 0.$$

This equality constraint is relaxed into a penalty term in the objective function for every obstacle, $\mu_O \psi_O(z)$, where μ_O is the penalty factor. The penalty method consists of solving the problem with higher and higher penalties, until the obstacles are avoided.

3 Results

The effectiveness of this algorithm has been tested for various obstacle configurations and multiple vehicle models using numerical simulations, benchmarking it against state-of-the-art interior point and SQP solvers. Figure 1 shows for example a vehicle with a trailer moving from different starting points to a destination while avoiding a crescent-shaped obstacle.

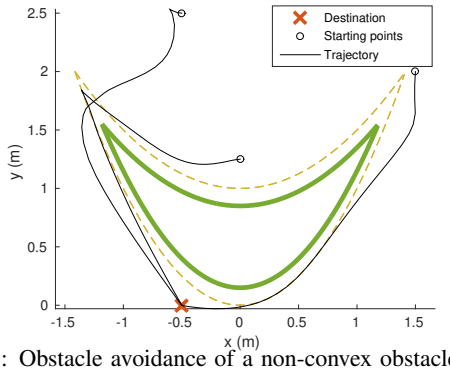


Figure 1: Obstacle avoidance of a non-convex obstacle, depicted by the thick green line. The enlarged obstacle (in dotted line) is defined by $O = \{(x,y) : y - x^2 > 0, 1 + 0.5 \cdot x^2 - y > 0\}$.

References

[1] L. Stella, A. Themelis, P. Sopasakis, and P. Patrinos, "A simple and efficient algorithm for nonlinear model predictive control," *arXiv preprint arXiv:1709.06487*, 2017.

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