Open Research @ Asta Zero Final Report

Traction Adaptive Motion Planning and Control at the Limits of Handling

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Executive summary

In this project we have experimentally evaluated our method for motion planning and control at the limits of handling, under locally varying traction conditions.

The experiments were performed on a on a Volvo FH16 heavy-duty vehicle, in a range of critical scenarios. Results indicate that traction adaptive motion planning and control improves the vehicle's capacity to avoid accidents, both when adapting to low and high local traction.

Background

The road traffic environment is inherently uncertain and unpredictable. An automated vehicle (AV) deployed in such an environment will eventually experience occurrences of unforeseen critical situations, i.e., situations in which an accident is imminent. Critical situations can occur for example due to sensory limitations, unexpected behavior from other road users, abrupt changes in operational conditions or due to internal faults of the AV. In such critical situations, passenger comfort is no longer a priority, and the full physical capacity of the vehicle should be employed if needed to avoid the imminent accident and take the vehicle to a safe state.

However, the physical limits of the vehicle varies substantially with the operational conditions. In this project, we tackle the problem of motion planning and control at the limits of handling, under locally varying traction conditions.

Purpose, research questions and method

The longer term research objective is to develop a mathematical and algorithmic framework that enables a vehicle to adapt its planned motion optimally, according to the prevailing traction conditions. The research question that has been guiding work throughout the project is:

- To what extent does consideration of time-varying actuation capability impact an AV's capacity to avoid accident in critical situations?

A case-study based research methodology has been applied, in which the traction adaptive motion planning and control scheme was compared to equivalent schemes with static representations of the traction limit, in selected critical scenarios. This project primarily includes the experimental evaluation in those scenarios.

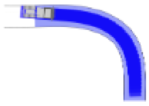
Results

Experiments in three primary scenarios were conducted in the project:

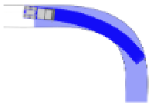
1. Turn at deteriorated traction conditions
2. Collision avoidance at deteriorated traction conditions
3. Collision avoidance at favorable traction conditions.

For all experiments, the friction coefficient of the track surface was measured beforehand such that properties of the motion planning and control functionality could be systematically studied without additional uncertainty from online friction estimation. A Volvo FH16 heavy-duty vehicle was used as a test vehicle.

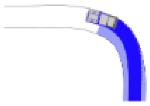
In the first scenario, the vehicle approaches a turn with deteriorated traction at 8m/s. The objective of the vehicle is to maintain its initial velocity and stay close to the center of the lane. Figure 1 shows a driving behavior analysis comparing the traction adaptive (TA) scheme with the non-adaptive (NA) scheme



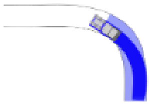
(a) NA, $t_c = 0$s



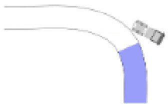
(b) TA, $t_c = 0$s



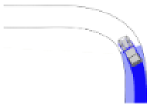
(c) NA, $t_c = 2.5$s (under-steering)



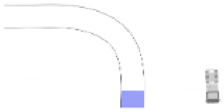
(d) TA, $t_c = 2.5$s



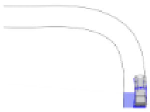
(e) NA, $t_c = 3.5$s (exiting lane)



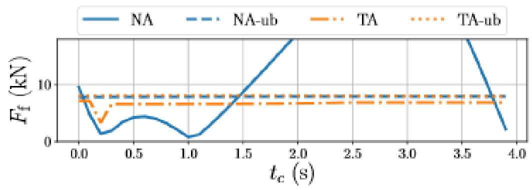
(f) TA, $t_c = 4$s



(g) NA, $t_c = 7$s (accident)



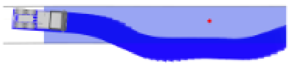
(h) TA, $t_c = 5$s (no accident)



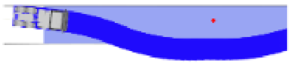
(i) Planned tire forces at $t_c = 0$s

Under the NA scheme, the vehicle plans to utilize very small tire forces at the beginning of the maneuver and very large ones in the later part of the maneuver (exceeding the physical limitations). This leads to substantial understeering and eventually loss of control and departure from the lane. In contrast, the TA scheme plans to utilize 90% of the available traction almost throughout the maneuver. In a coordinated manner, it positions the vehicle along the outside of the track before the corner, crosses over first to the inside of the lane at the middle of the corner and then back to the outside of the lane towards the end of the turn, while braking at the same time to reduce the speed of the vehicle.

In the second scenario, a pedestrian is detected 20m ahead of the vehicle. The initial velocity is 8m/s and the traction conditions are the same as in scenario 1. Figure 2 shows a driving behavior analysis.



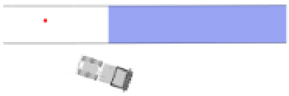
(a) NA, $t_c = 0$s



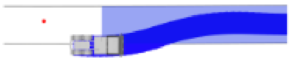
(b) TA, $t_c = 0$s

(c) NA, $t_c = 2$s **(under-steering)**

(d) TA, $t_c = 2$s



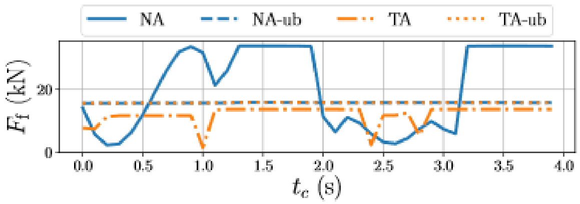
(e) NA, $t_c = 3.1$s **(exiting lane)**



(f) TA, $t_c = 3.1$s

(g) NA, $t_c = 5$s **(accident)**

(h) TA, $t_c = 5$s, **(no accident)**



(i) Planned tire forces at $t_c = 0$s

Under the NA scheme, the vehicle plans an aggressive evasive maneuver that quickly moves out of the path of the obstacle. In doing so, it plans tire forces that exceed the physical limitations (Fig 2i). Again, this leads to substantial initial understeering and eventually to a complete loss of control and departure from the lane. In contrast, the TA scheme plans to utilize maximum 90% of the available traction, resulting in a smoother, less aggressive evasive maneuver that evades the obstacle without losing control of the vehicle.

The trivial solution to handling scenarios 1 and 2 with static tire force constraints is to select a conservative static tire force constraint corresponding to worst case conditions. This however will restrict the maneuverability of the vehicle in good conditions, as we shall see in the next scenario.

In the third scenario, the vehicle is travelling at 15m/s on a dry road surface when a pedestrian is detected 15m ahead of the vehicle. Figure 3 shows a driving behavior analysis.

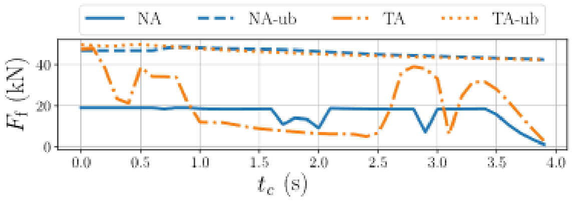
(a) NA, $t_c = 0$s

(b) TA, $t_c = 0$s

(c) NA, $t_c = 0.7$s (accident)

(d) TA, $t_c = 0.7$s (evading)

(e) TA, $t_c = 3$s (no accident)



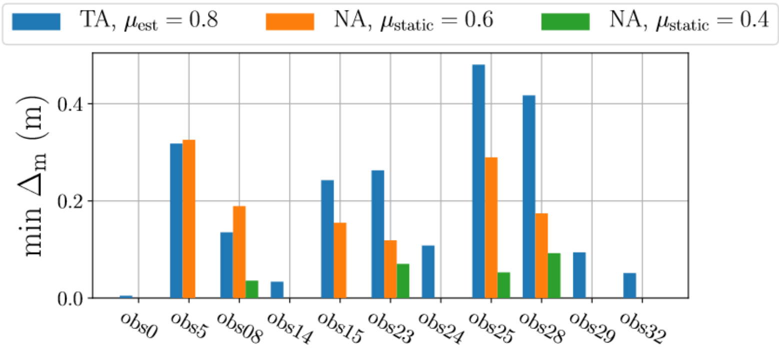
(f) Planned tire forces at $t_c = 0$s

Under the NA scheme with a conservative tire force constraint, the planner is unable to find a plan that is both feasible with respect to the tire force constraints and avoiding the obstacle. It selects the least violating option and consequently collides with the obstacle. The TA scheme on the other hand allows opening up the tire force constraints according to the favorable traction conditions, allowing a more aggressive evasive maneuver that avoids collision.

This experiment was repeated 120 times in total for three settings of the algorithm:

1. Traction adaptive
2. Non-adaptive with moderately conservative static tire force constraints
3. Non-adaptive with very conservative tire force constraints

Results are displayed in Figure 4.



Configuration 1 managed to avoid 11/40 repetitions, whilst configurations 2 and 3 manages 6/40 and 4/40 respectively. Furthermore, Figure 4 shows that a larger degree of conservativeness tends to lead to a smaller distance margin to the avoided obstacles.

Conclusion and outlook

The conclusions from the experimental evaluation conducted within the project are:

1. Considering time-varying actuation capability improves the vehicle's capacity to avoid accident in critical situations.

2. For collision avoidance, performance in this regard increases both when adapting to high and low local traction.

This stems from two key properties of the motion planning and control framework

1. Ensured dynamic feasibility of planned motions, even in the presence of deteriorated actuation capability.

2. A high ratio (90% for the tested configuration) of locally available actuation capacity is utilized to avoid accident if necessary.

This round of experiments were conducted with the tire-road friction coefficient having been estimated ahead of time. For the purposes of a scientific study this is reasonable, but for deployment in a real AV, the motion planning and control scheme will be integrated with a method for friction estimation based on traditional estimation techniques or computer vision.

Lessons learned, experience from testing at AstaZero

For this type of work, experimental evaluation is crucial for learning the true potential of an algorithm. Development of the algorithms continued through the first half of experiments at Asta, based on new knowledge that could only be acquired at the track.

Many technical challenges appeared along the way, but none that hindered or altered the scope of the project in any way. The team involved in the project (see below) were organized and professional and managed to deal with each of the challenges one by one.

There was a bit of lead time before the project first took off, but in hindsight this was not all bad. It gave the team (myself in particular) more time to prepare the software framework such that when we could be efficient at the track once the project took off.

Publication and dissemintion (incl. planned)

The expereimental work conducted within this project has so far lead to one submission to IEEE Transactions on Control System Technology.

Preprint available here: https://arxiv.org/abs/2009.04180

Videos: https://www.youtube.com/watch?v=DAqig5euQ30 ,
https://www.youtube.com/watch?v=k5rIzal_O2A ,
https://www.youtube.com/watch?v=qGlLcbszRwE

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