Driver assistance system design A

Autonomous maneuvers

Carlo Novara

Politecnico di Torino
Dip. Elettronica e Telecomunicazioni

Outline

SAE **J3016**™ LEVELS OF DRIVING AUTOMATION™

Learn more here: sae.org/standards/content/j3016_202104

	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Introduction

- **SAE level 2 and higher levels**: The automated system takes control of the vehicle: accelerating, braking, and steering.
  - Vehicle control is based on lateral and longitudinal control (lane keeping and cruise control).
  - The joint use of these two technologies allows the vehicle to accomplish autonomous maneuvers.
- NMPC can jointly perform lateral and longitudinal control.
- Lateral/longitudinal control algorithms are supported by higher level blocks:
  - Decision Making Module (DMM): in charge of deciding the maneuver the ego vehicle has to accomplish.
  - Path planning/trajectory planning algorithm: in charge of planning a suitable trajectory to track.

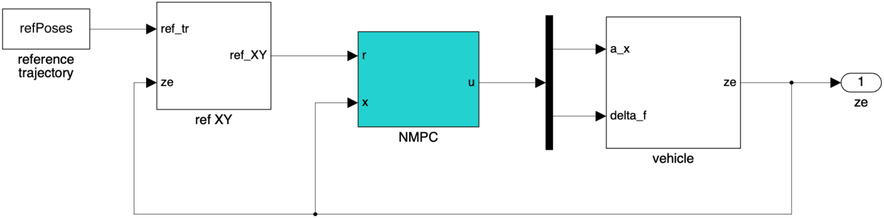
Introduction

Trajectory planning and control

- Global trajectory planning (path planning): Find an optimal path between two points on a map, avoiding obstacles.
- Local trajectory planning: Similar to the global one but:
  - The trajectory is planned over a shorter time interval.
  - The planned trajectory must be consistent with the vehicle dynamics.
  - The trajectory is planned in real-time.
- Trajectory planning and control: Trajectory planning + providing the control command that makes the vehicle track the planned trajectory.
- NMPC can jointly perform local trajectory planning and control.

Autonomous maneuvers

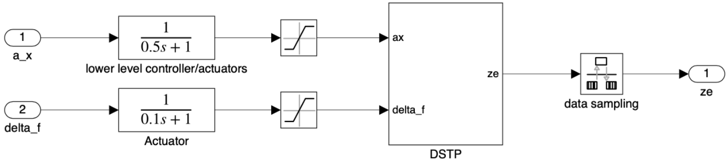
Closed-loop scheme



- vehicle: DSTP model with input (a_x, δ_f).
- NMPC: on-line solution of an optimization problem - receding horizon strategy.
- reference trajectory: set of points giving the whole reference trajectory (from a global planner).
- ref XY: on-line computation of the reference trajectory segment corresponding to the prediction time interval $[t, t + T_p]$.

Autonomous maneuvers

Vehicle model



- DSTP: dynamic single-track vehicle model with Pacejka's tire formula and input $u = (a_x, \delta_f)$.
  - Vehicle parameters: $l_f = 1.2\,\mathrm{m}$, $l_r = 1.6\,\mathrm{m}$, $m = 1575\,\mathrm{kg}$, $J = 4000\,\mathrm{kg\,m^2}$, $c_f = 27e3\,\mathrm{N/rad}$, $c_r = 20e3\,\mathrm{N/rad}$.
  - Tire parameters: $p_1 = \xi\,3863\,\mathrm{N}$, $\xi \in [0,1]$, $p_2 = 1.5$, $p_4 = -0.5$, $p_3 = c_f/p_1/p_2$ (front tire) or $p_3 = c_r/p_1/p_2$ (rear tire).
- Other blocks:
  - actuators
  - saturations ($a_x \in [-10, 3] \cdot 10^4\,\mathrm{m/s^2}$, $\delta_f \in [-0.4, 0.4]\,\mathrm{rad}$)
  - data sampling block (sampling time $0.05\,\mathrm{s}$).

Autonomous maneuvers

NMPC control design

- NMPC design:
  - prediction model: DSTA model = DST model with $\beta_f = \operatorname{atan}\left(\frac{v_y + l_f \omega_\psi}{v_x}\right) - \delta_f$ and $\beta_r = \operatorname{atan}\left(\frac{v_y - l_r \omega_\psi}{v_x}\right)$ (no Pacejka's formula; parameters difficult to measure/estimate in real scenarios);
  - plant input: $u = (a_x, \delta_f)$;
  - output: $y = (X, Y)$ (other options: (X, Y, ψ), (e_{ct}, e_h), (e_y, e_ψ));
  - $T_s = 0.05\,\mathrm{s}$, $T_p = 3\,\mathrm{s}$;
  - weight matrices: $R = \mathrm{diag}(0.1, 0.5)$, $Q = \mathrm{diag}(5, 5)$, $P = \mathbf{0}$;
    - R penalizes high accelerations and steering angles;
  - input constraints: $u_1 \in [-10, 3]\,\mathrm{m/s^2}$, $u_2 \in [-0.4, 0.4]\,\mathrm{rad}$;
  - no state and output constraints.
- This controller is used in all the maneuvers considered in the following, with possible inclusion of state/output constraints.

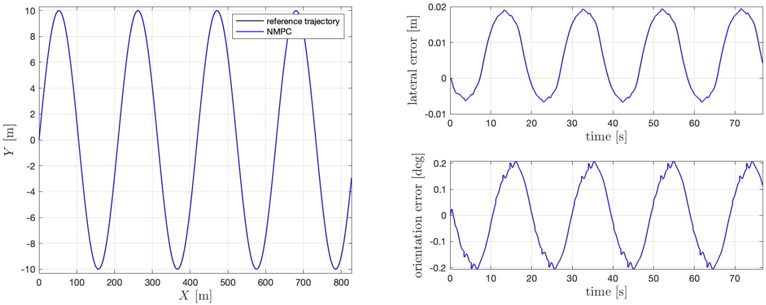
1. Introduction

2. Autonomous maneuvers

3. Simulation results

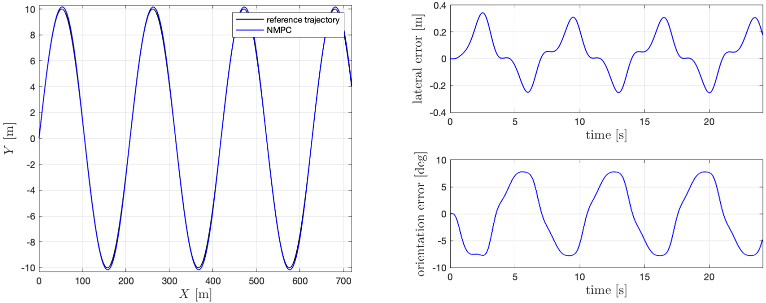
Autonomous maneuvers

Simulation results. Sinusoidal road, $v_x = 40\,\mathrm{km/h}$, dry.



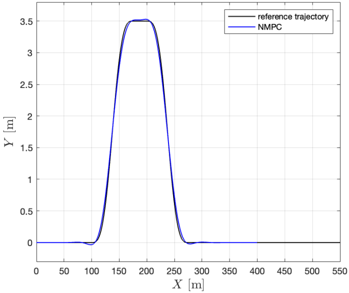
Autonomous maneuvers

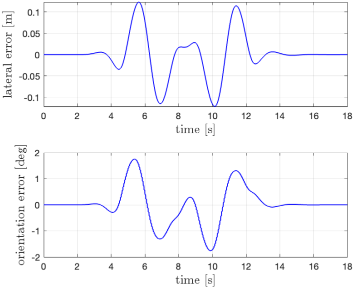
Simulation results. Sinusoidal road, $v_x = 100\,\mathrm{km/h}$, dry.



Autonomous maneuvers

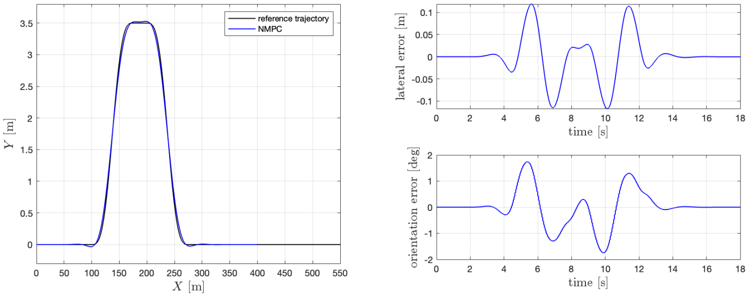
Simulation results. Double lane change, $v_x = 80\,\mathrm{km/h}$, dry.





Autonomous maneuvers

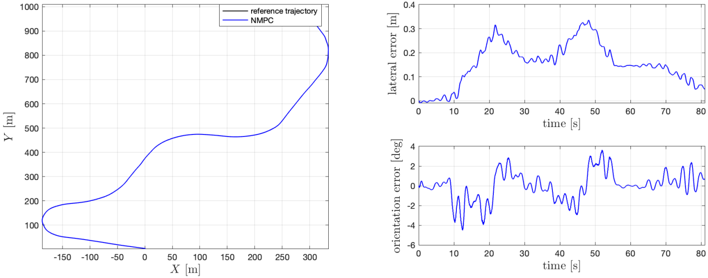
Simulation results. Double lane change, $v_x = 80\,\mathrm{km/h}$, wet.



- In general, NMPC does not need VSC.

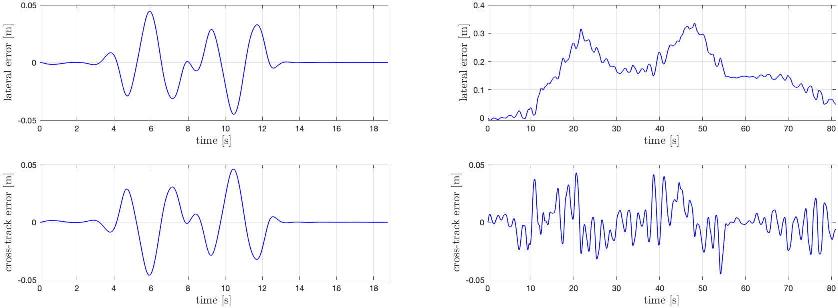
Autonomous maneuvers

Simulation results. Real road, $v_x = 60\,\mathrm{km/h}$, dry.



Autonomous maneuvers

Lateral and cross-track errors.



- The lateral and cross-track errors are both useful for control design, implementation and test.
- Cross-track error perhaps more reliable.

Autonomous maneuvers

Simulation results. Obstacle avoidance, $v_x = 70\,\mathrm{km/h}$, dry road.

- Same design as above, but with the following trajectory constraint:

$$\|(X, Y) - (X_{con}, Y_{con})\| \geq 2$$

  where (X_{con}, Y_{con}) is the position of an obstacle.
- The simulation shows that NMPC
  - allows obstacle avoidance;
  - can accomplish local trajectory planning (combined with control).