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XXXIV Cycle - II year presentation

C-ITS services and advanced vehicle control for complex traffic scenarios

RESEARCH TOPIC

- Development of innovative C-ITS control systems to enhance the performance of autonomous/automated and connected road vehicles.
- Application of control approaches to Cooperative Intelligent Transportation System (C-ITS), e.g. autonomous and connected vehicles in urban and extra-urban scenarios, mixed traffic flow (i.e. with human-driven vehicles (HDV), smart road intersections, smart cities, communication infrastructures.

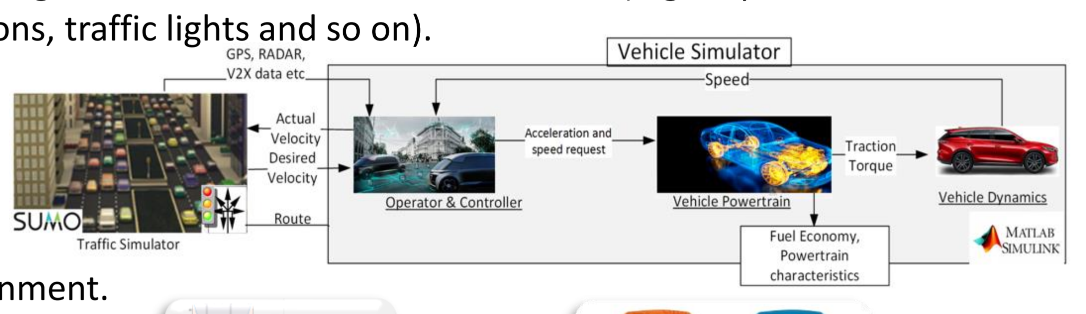
MOTIVATIONS

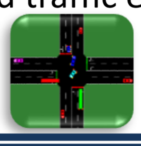
- Development and validation of C-ITS control strategies are usually performed in simplified conditions, e.g. simplified/neglected road traffic environment, predefined manoeuvrers and linear vehicle dynamics model.
- The aim of the research is to develop, test and validate innovative C-ITS strategies for autonomous and connected vehicles in order to increase autonomous driving safety in complex mixed traffic flow.
- The idea is to tailor the theoretical results with respect to practical problems, e.g. mixed traffic flow, heterogeneous vehicles and nonlinear uncertain vehicles models.

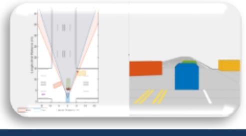
MiTraS SIMULATION PLATFORM

Mixed Traffic Simulator (MiTraS) co-simulation platform has been designed and implemented for validating different control strategies in realistic road traffic scenarios (e.g. in presence of human-driven vehicles, road intersections, traffic lights and so on).

- Matlab/Simulink
  - Vehicle Dynamics;
  - Sensors;
  - 3D road environment;
- SUMO for road traffic environment.

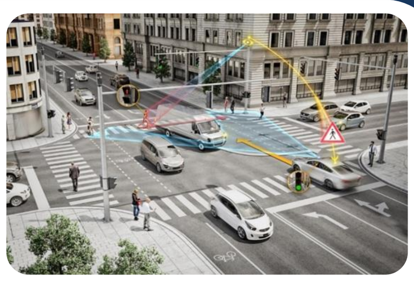






TRAFFIC SCENARIOS

- Urban traffic scenarios:
  - Unsignalized/Signalized intersection;
  - Pedestrian and cyclists ;
  - Turn maneuver;
  - Emergency Breaking.
- Extra-urban traffic scenarios:
  - Platooning;
  - Lane change/overtaking maneuver;
  - Breakdown phenomena;
  - Road section restriction;
  - Emergency Breaking.



COOPERATIVE CONTROL STRATEGY FOR HETEROGENEOUS NONLINEAR UNCERTAIN AUTONOMOUS VEHICLES PLATOON

- Nonlinearities have to be considered for a more accurate and realistic problem formulation and control design;
- Robustness w.r.t. uncertain nonlinear dynamics is crucial in cooperative driving applications to deal with mismatches between the actual plant and its control-oriented model;
- Maneuvers, such as join and leave the platoon, must be performed considering the surrounding traffic conditions.
- Each nonlinear heterogeneous autonomous vehicle ***i*** is modelled as:

$$\dot{p}_i(t) = v_i(t)$$

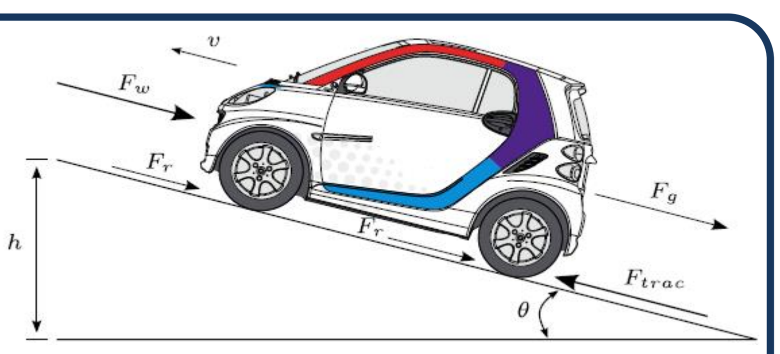
$$\dot{v}_i(t) = f_i(v_i(t)) + b_i(t)u_{i,\sigma}(t).$$

$$\dot{v}_i(t) = \frac{\eta_i(t)}{R_i(t)m_i(t)}u_{i,\sigma}(t) - gsin(\theta) - gf_{r,i}(t)cos(\theta) - \frac{0.5}{m_i(t)}\rho C_{D,i}(t)(1-\phi_i)C_{h,i}(t)A_{f,i}(t)v_i^2(t).$$

$$C_{D,i}(t) = \bar{C}_{D,i} + \delta C_{D,i}(t),\quad C_{h,i}(t) = \bar{C}_{h,i} + \delta C_{h,i}(t),\quad A_{f,i}(t) = \bar{A}_{f,i} + \delta A_{f,i}(t),$$

$$R_i(t) = \bar{R}_i + \delta R_i(t),\quad f_{r,i}(t) = \bar{f}_{r,i} + \delta f_{r,i}(t),$$

$$m_i(t) = \bar{m}_i + \delta m_i(t),\quad \eta_i(t) = \bar{\eta}_i + \delta\eta_i(t),$$



PROPOSED SOLUTION

Algorithm 1 Motion Control Strategy

Data: Neighbors Information $x_j(t)$.
Result: Control Input $u_{i,\sigma}(t)$.
Declarations
out_i = [0,1];
N = number of vehicles within the platoon;
t_s = manoeuvre start time;
c_f = collision flag.
Initialization
$N = 5$.
Scenario 1: $out_i = 0,\ i = (1,\dots,N)$;
Scenario 2: $out_3 = 1$;
$out_i = 0,\ i = (1,\dots,N)\ \&\ i \neq 3$;
$T_m = 50$.
Distributed Robust PI Control Action

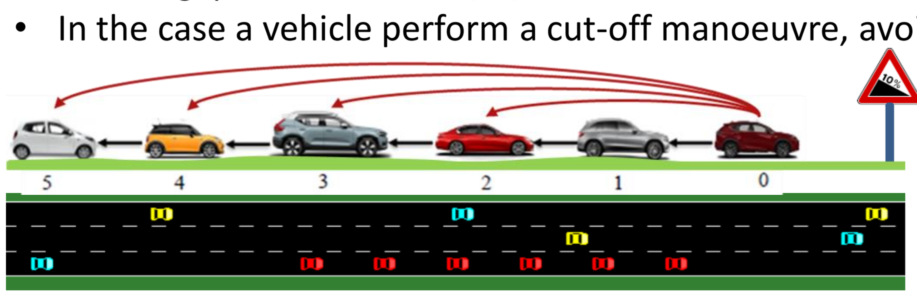
$$u_{i,\sigma}(t) = -\alpha_\sigma \bar{b}_i^{-1}K_{p,\sigma}\sum_{j=0}^{N} a_{ij,\sigma}\Big(p_i(t) - p_j(t) - d_{ij}\Big) - \alpha_\sigma \bar{b}_i^{-1}K_{i,\sigma}\sum_{j=0}^{N} a_{ij,\sigma}\int_0^t \Big(p_i(\tau) - p_j(\tau) - d_{ij}\Big)d\tau - \alpha_\sigma \bar{b}_i^{-1}K_{d,\sigma}\sum_{j=0}^{N} a_{ij,\sigma}\Big(v_i(t) - v_j(t)\Big).$$

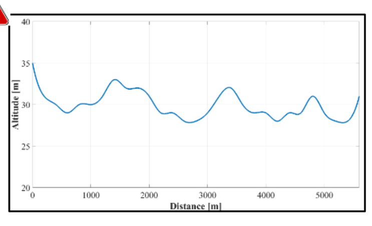
Motion Control

```
for i=1 to N do
  if out_i == 1 & t ≥ T_m then
    Generate reference lane-change trajectory;
    Detect any foes HDVs for the generated trajectory;
    if c_f is OFF then
      Start the lane change manoeuvre;
    else
      Wait to start the lane-change manoeuvre;
      Compute the distributed robust PI control action;
    end
  else
    Compute the distributed robust PI control action;
  end
end
```

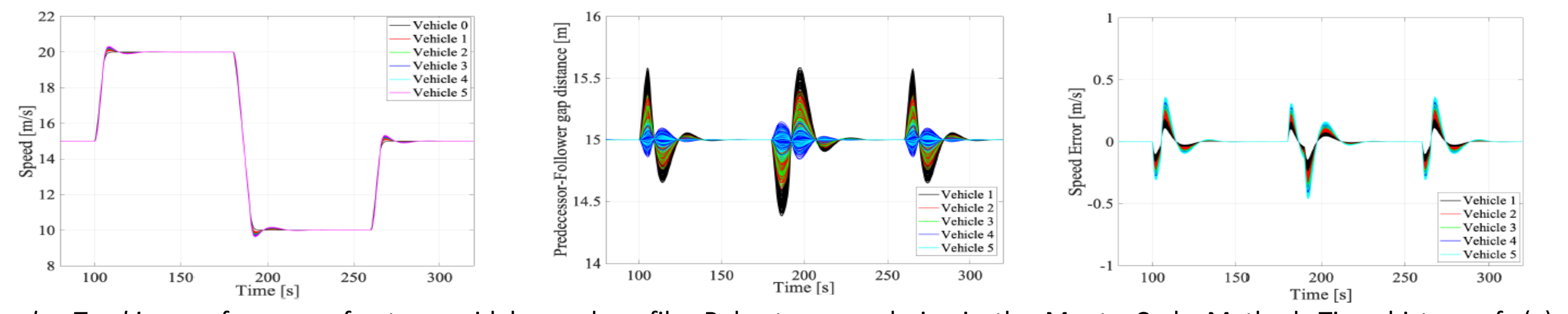
HETEROGENEOUS NONLINEAR UNCERTAINPLATOONING APPLICATION

- The aim is to guarantee that each vehicle within the platoon tracks the leader speed while preserving a desired inter-vehicle gap distance of *15 [m];*
- In the case a vehicle perform a cut-off manoeuvre, avoiding collision with HDVs, the platoon has to be recreated.

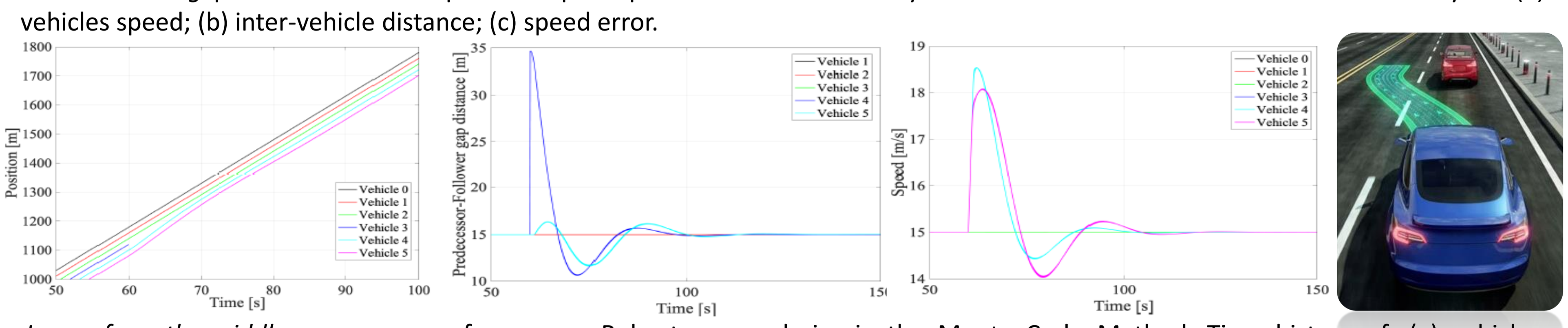




Vehicle Parameters	m_i [kg]	η_i [−]	R_i [m]	f_{ri} [−]	$C_{D,i}$ [−]	$A_{f,i}$ [m^2]	a_{max} [m/s^2]	a_{min} [m/s^2]
0	1545	0.89	0.3060	0.020	0.28	2.3315	2.5	-6.0
1	1015	0.89	0.2830	0.022	0.30	2.1900	2.5	-6.0
2	1375	0.89	0.2880	0.019	0.24	2.4000	2.5	-6.0
3	1430	0.89	0.3284	0.021	0.28	2.4600	2.5	-6.0
4	1067	0.89	0.2653	0.023	0.29	2.1400	2.5	-6.0
5	1155	0.89	0.2880	0.024	0.33	2.0400	2.5	-6.0
Uncertainty	±20%	±5%	±2%	±10%	±10%	±10%	-	-



Leader Tracking performance for trapezoidal speed profile. Robustness analysis via the Monte Carlo Method. Time history of: (a) vehicles speed; (b) inter-vehicle distance; (c) speed error.



Leave from-the-middle maneuver performances. Robustness analysis via the Monte Carlo Method. Time history of: (a) vehicles position; (b) inter-vehicle distance; (c) vehicles speed.

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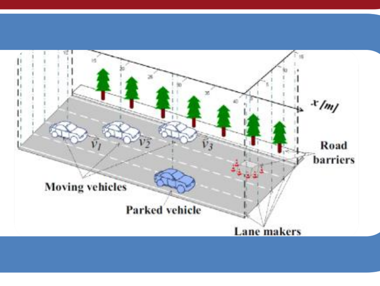
FUTURE WORKS

- Design of controllers able to deal with different spacing policies.

- Cooperative Control at unsignalized intersection in presence of mixed traffic flow.

- Safe navigation in presence of several different obstacles.



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