Distributed consensus strategy for platooning in presence of delays

Elective in Robotics - Control of multi robot systems

Sapienza Università di Roma

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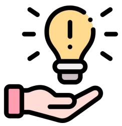
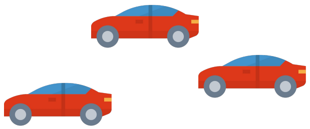
How the presentation is organized



Introduction and preliminaries

Section 1 - Problem statement

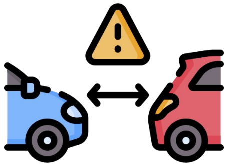


Section 2 - Closed-loop vehicular network control

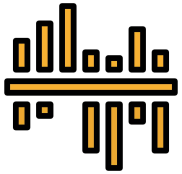
Section 3 - MATLAB implementation

Section 4 - Results

Introduction and preliminaries



Main goal: control vehicles to form a platoon and maintain optimal spacing policy

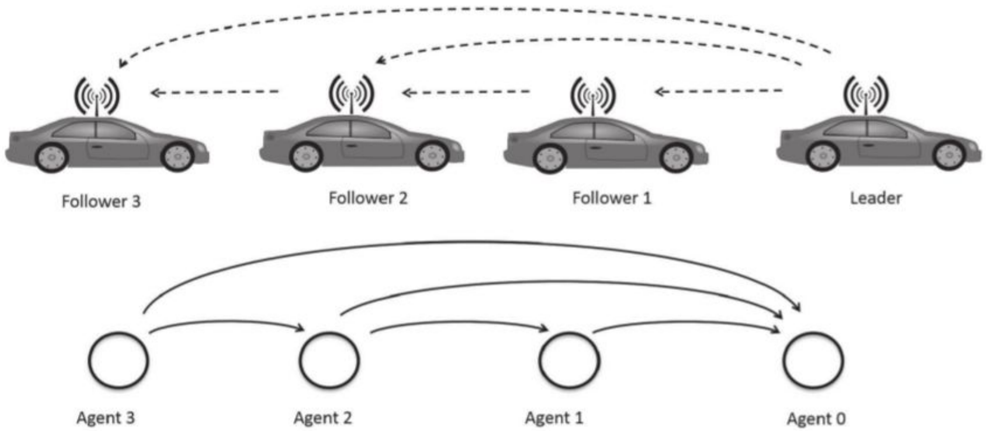


Theoretical analysis used to prove string stability, i.e perturbations on the leader are not amplified

Introduction and preliminaries

Dynamical network paradigm:

- vehicles are nodes with their own dynamic
- communications between vehicles are represented as edges
- the network topology encodes intervehicles communications



N = 4 vehicles + leader vehicles

Section 1 - problem statement

- single lane straight trajectory
- V2V sharing of local absolute position, velocity, acceleration
- string leader - follower configuration
- reference velocity is given from the leader (v0)

state vector

$$\eta_i = [\eta_i^{(1)}, \eta_i^{(2)}]^\top = [r_i, v_i]^\top \in \mathbb{R}^2.$$

dynamic model as a linear integrator:

$$\dot{r}_i(t) = v_i(t), \quad \dot{v}_i(t) = \frac{1}{M_i} u_i(t)$$

leader configuration

$$\dot{r}_0(t) = v_0, \quad \dot{v}_0 = 0.$$

Section 1 - problem statement

state vector $\eta_i = [\eta_i^{(1)}, \eta_i^{(2)}]^\top = [r_i, v_i]^\top \in \mathbb{R}^2.$

the problem of maintaining a desired intervehicle spacing policy and a common velocity can be formulated as a second-order consensus problem

$$\boxed{r_i(t) \to \frac{1}{d_i}\left\{\sum_{j=0}^{N} a_{ij} \cdot (r_j(t) + d_{ij})\right\}, \quad v_i(t) \to v_0}$$

d_{ij} are the desired spacing errors between agents

$$d_{ij} = h_{ij} v_0$$

h_{ij} being the *constant time headway*

$d_i = \sum_{j=0}^{N} a_{ij}$ is the degree of agent i

elements of the adjacency matrix of graph $\mathcal{G}_{N+1}$

Section 1 - problem statement

$$r_i(t) \to \frac{1}{d_i}\left\{\sum_{j=0}^{N} a_{ij}\cdot(r_j(t)+d_{ij})\right\}, \quad v_i(t) \to v_0$$

This consensus target can be rewritten in:

$$\boxed{r_i(t) \to r_0(t) + d_{i0}, \quad v_i(t) \to v_0}$$

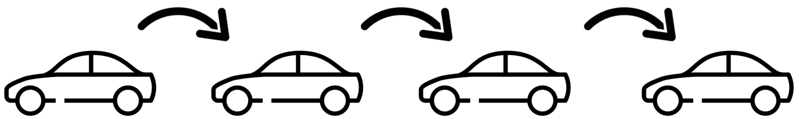
It can be achieved applying a distributed strategy

Section 1 - problem statement

$$r_i(t) \rightarrow r_0(t) + d_{i0}, \quad v_i(t) \rightarrow v_0$$

It can be achieved applying a distributed strategy:

- all vehicles transmit their state to the i-th vehicles together with ID and timestamp t



The i-th vehicle adjusts its dynamics through this decentralized coupling protocol computed onboard

$$u_i = -b\left[v_i(t) - v_0\right] + \frac{1}{d_i}\sum_{j=0}^{N} k_{ij}a_{ij} \cdot (\tau_i(t)v_0) - \frac{1}{d_i}\sum_{j=0}^{N} k_{ij}a_{ij} \cdot \left(r_i(t) - r_j\left(t - \tau_i(t)\right) - h_{ij}v_0\right) \quad (9)$$

Section 1 - problem statement

Parameters to specify:

1. stiffness and damping and parameter

   $k_{ij} > 0$ and $b > 0$

2. communication delays

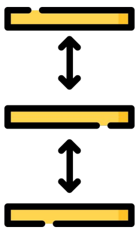
   $\tau_i(t)$ is the *aggregate delay*

   $\tau_{\min} \leq \tau_i(t) \leq \tau_{\max}$

   In the paper it is a bounded stochastic piecewise constant function

$$\boxed{\begin{aligned} u_i = -b\left[v_i(t) - v_0\right] + \frac{1}{d_i}\sum_{j=0}^{N} k_{ij}a_{ij}\cdot\left(\tau_i(t)v_0\right) - \frac{1}{d_i}\sum_{j=0}^{N} k_{ij}a_{ij} \\ \cdot\left(r_i(t) - r_j\left(t - \tau_i(t)\right) - h_{ij}v_0\right) \quad (9) \end{aligned}}$$

Section 2 - closed loop vehicular control



$$u_i = -b\bar{v}_i(t) - \frac{1}{d_i}\sum_{j=0}^{N} k_{ij}a_{ij} \cdot \left(\bar{r}_i(t) - \bar{r}_j\left(t - \tau_i(t)\right)\right). \quad (11)$$

Defining the error as:

$\bar{r}_i = (r_i(t) - r_0(t) - h_{i0}v_0)$, and $\bar{v}_i = (v_i(t) - v_0)$.

h_{ij} being the *constant time headway*

$$\bar{r} = [\bar{r}_1, \ldots, \bar{r}_i \ldots, \bar{r}_N]^\top$$
$$\bar{v} = [\bar{v}_1, \ldots, \bar{v}_i \ldots, \bar{v}_N]^\top$$

$$u_i = -b[v_i(t) - v_0] + \frac{1}{d_i}\sum_{j=0}^{N} k_{ij}a_{ij} \cdot (\tau_i(t)v_0) - \frac{1}{d_i}\sum_{j=0}^{N} k_{ij}a_{ij} \cdot \left(r_i(t) - r_j\left(t - \tau_i(t)\right) - h_{ij}v_0\right) \quad (9)$$

Quick recap - the controller

dynamic model

$$\dot{r}_i(t) = v_i(t), \quad \dot{v}_i(t) = \frac{1}{M_i} u_i(t)$$

state

$$\eta_i = [\eta_i^{(1)}, \eta_i^{(2)}]^\top = [r_i, v_i]^\top \in \mathbb{R}^2.$$

leader

$$\dot{r}_0(t) = v_0, \quad \dot{v}_0 = 0.$$

error

$$\bar{r} = [\bar{r}_1, \ldots, \bar{r}_i \ldots, \bar{r}_N]^\top$$
$$\bar{v} = [\bar{v}_1, \ldots, \bar{v}_i \ldots, \bar{v}_N]^\top$$

control

$$u_i = -b\bar{v}_i(t) - \frac{1}{d_i} \sum_{j=0}^{N} k_{ij} a_{ij} \cdot (\bar{r}_i(t) - \bar{r}_j(t - \tau_i(t))) . \quad (11)$$

Control input

- acting on each vehicle
- composed of two terms:
  - local action
  - action depending on neighbours

Section 3 - MATLAB implementation

`init_test.m`

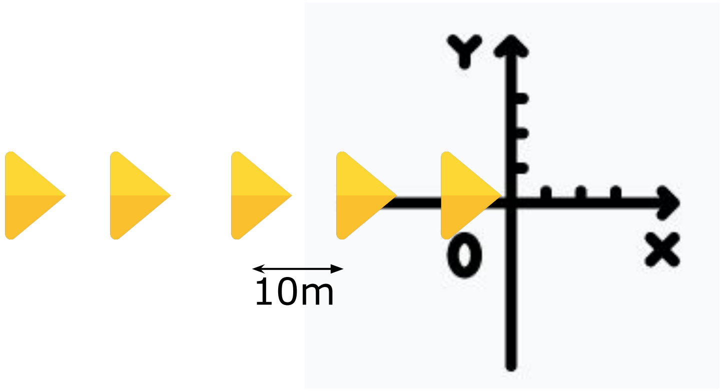
`model.slx`

GitHub

Section 4 - MATLAB implementation

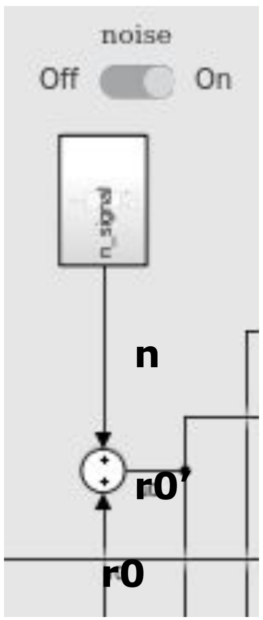
Initial conditions setup

1. [r0, v0] = [0, 20]
2. h_i0 = -i*0.8
3. noise = 0 or 1
4. [r, v] = [-i*10 , 0]

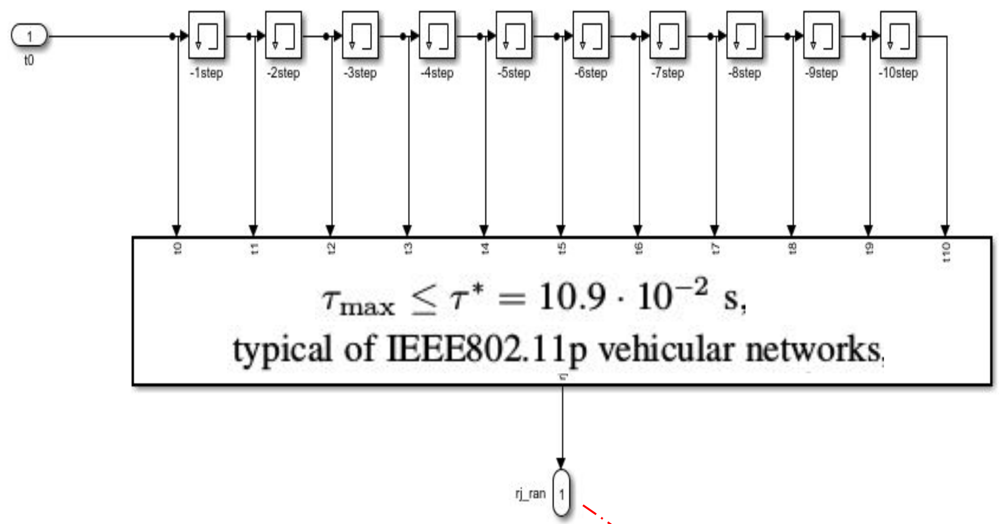


Section 3 - MATLAB implementation

Leader position noise block



Communication delay block

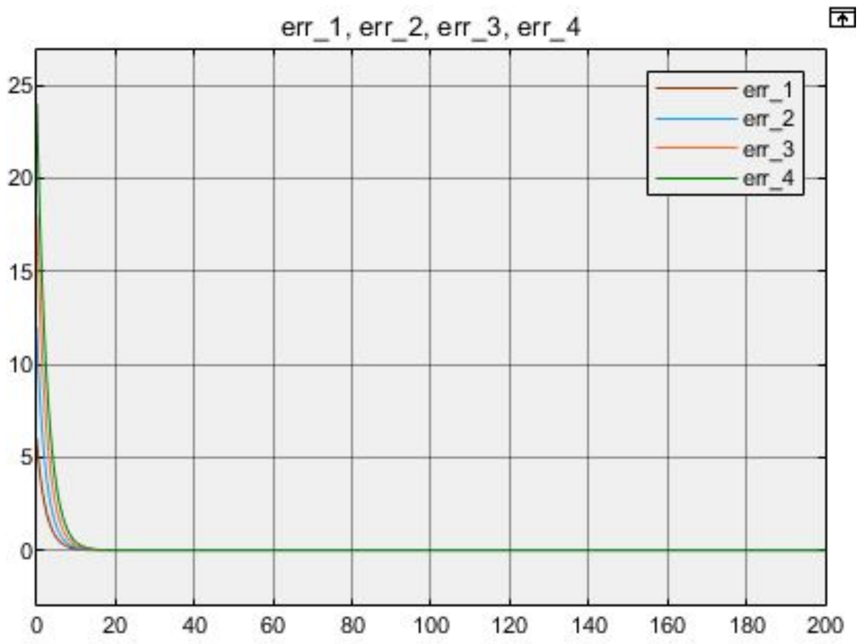


$$u_i = -b\bar{v}_i(t) - \frac{1}{d_i}\sum_{j=0}^{N} k_{ij}a_{ij} \cdot \left(\bar{r}_i(t) - \bar{r}_j\left(t - \tau_i(t)\right)\right). \quad (11)$$

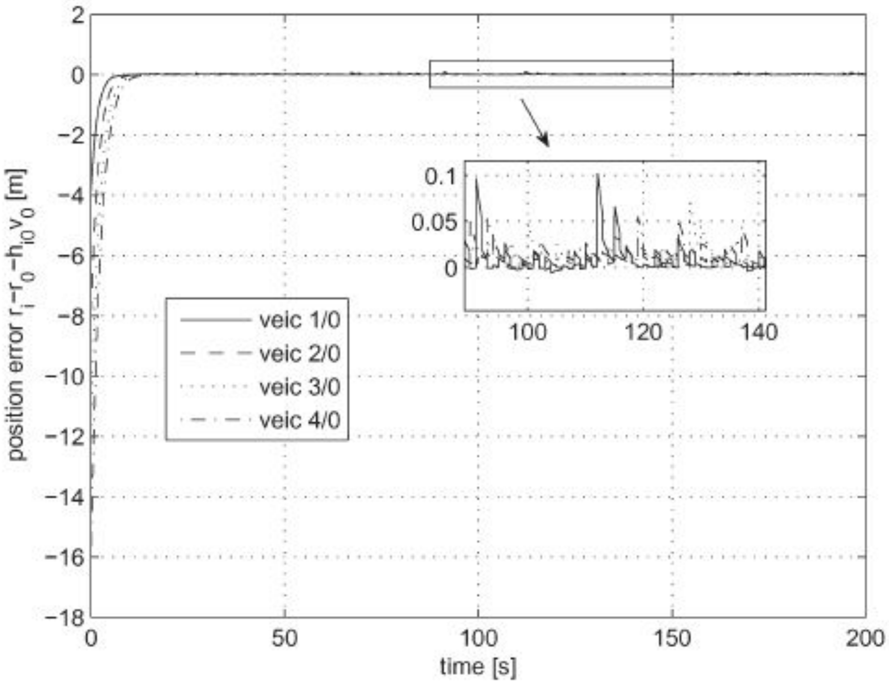
Section 4 - Experiment (1a)

In this experiment we've simulated the platoon in **absence of sinusoidal noise** on the leader

Our position error



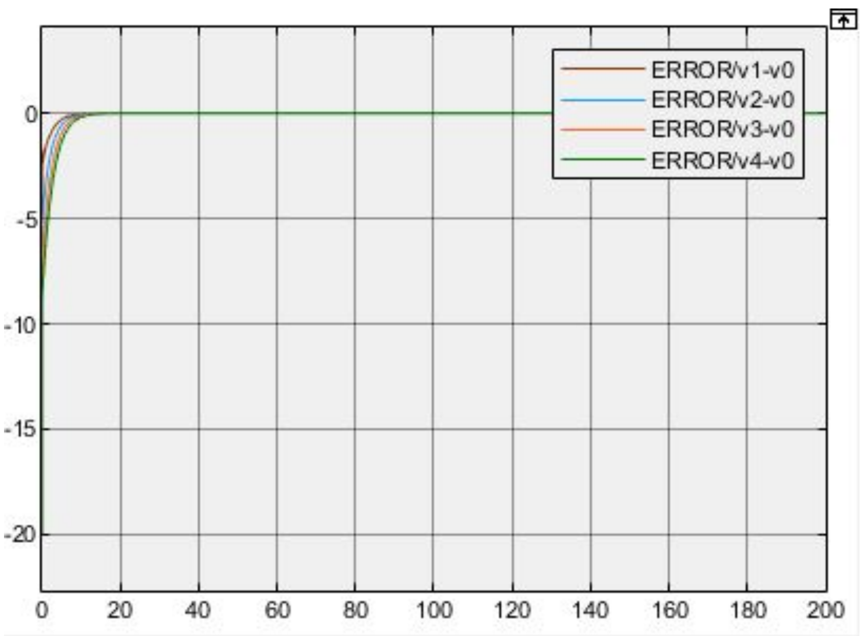
Paper position error



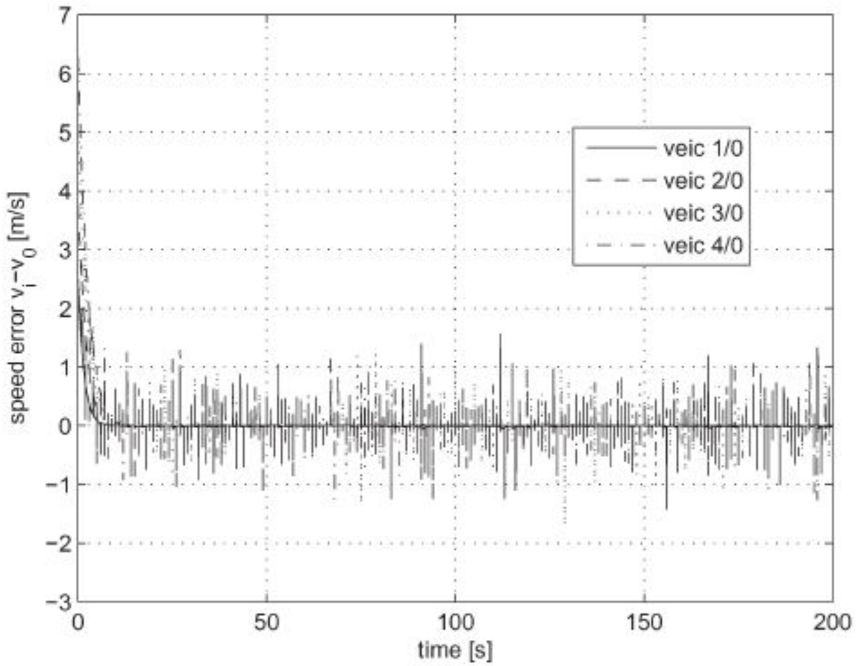
Section 4 - Experiment (1b)

In this experiment we've simulated the platoon in **absence of sinusoidal noise** on the leader

Our speed error



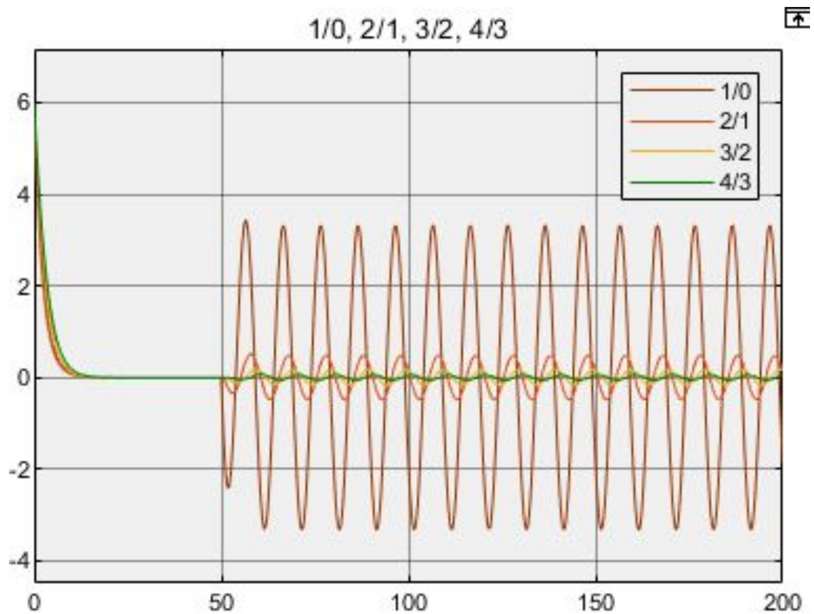
Paper speed error



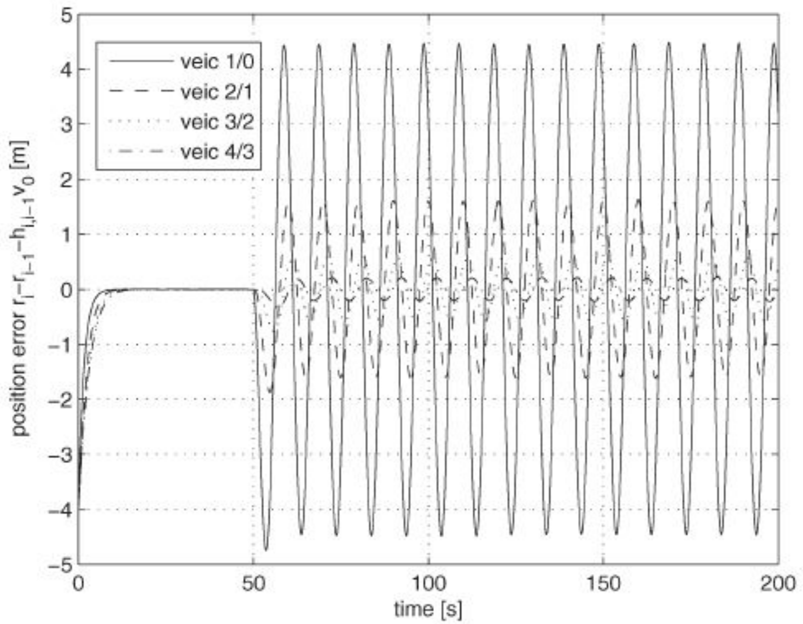
Section 4 - Experiment (2a)

In this experiment we've simulated the platoon in **presence of sinusoidal noise** on the leader

Our position error



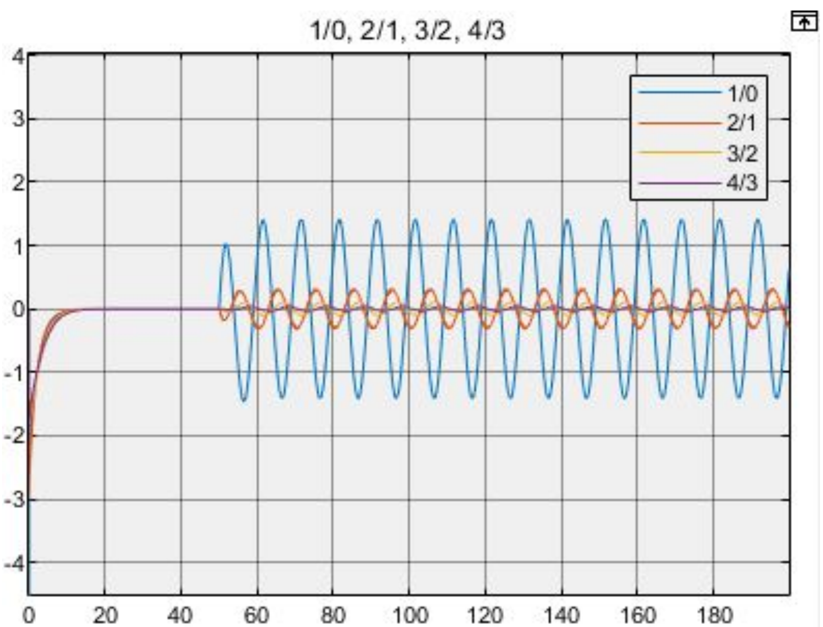
Paper position error



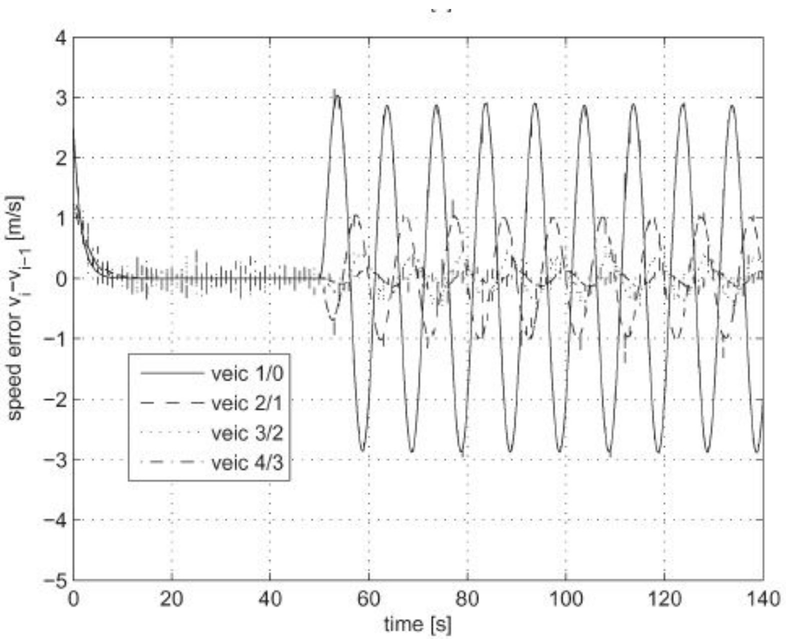
Section 4 - Experiment (2b)

In this experiment we've simulated the platoon in **presence of sinusoidal noise** on the leader

Our speed error



Paper speed error



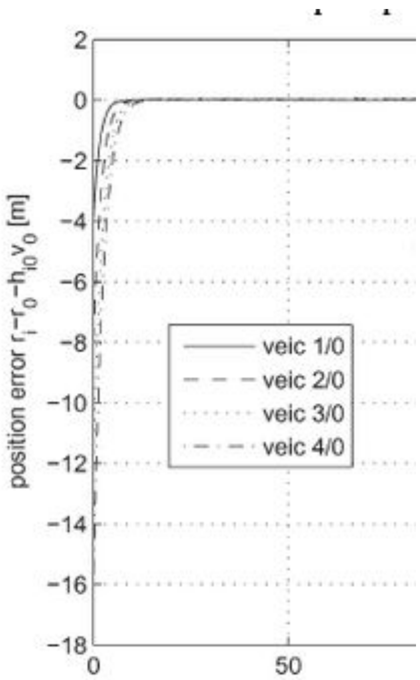
Conclusions (1)

Their assumptions:

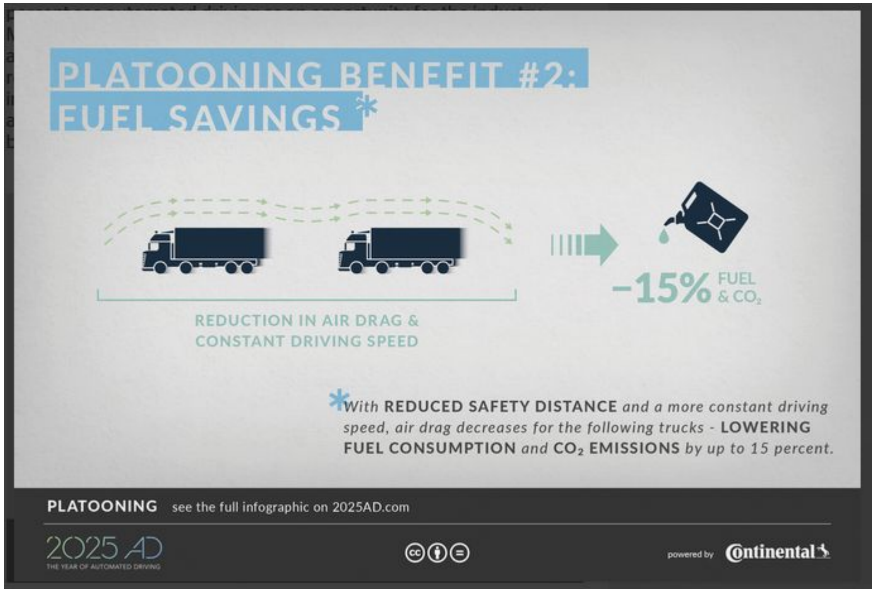
1. Leader starts with an initial velocity of 20 m/s
2. Vehicles start at a distance greater than the spacing policy
3. Initial velocities of platoon members greater than leader velocity

Our assumptions:

1. Leader starts with an initial velocity of 20 m/s
2. Vehicles start with a distance
3. Initial velocity for all vehicles equal to 0



Conclusions (2)



2025 AD
DRIVEN BY DRIVERLESS

Conclusions (end)