Simulation and control of a heterogeneous fleet of vehicles

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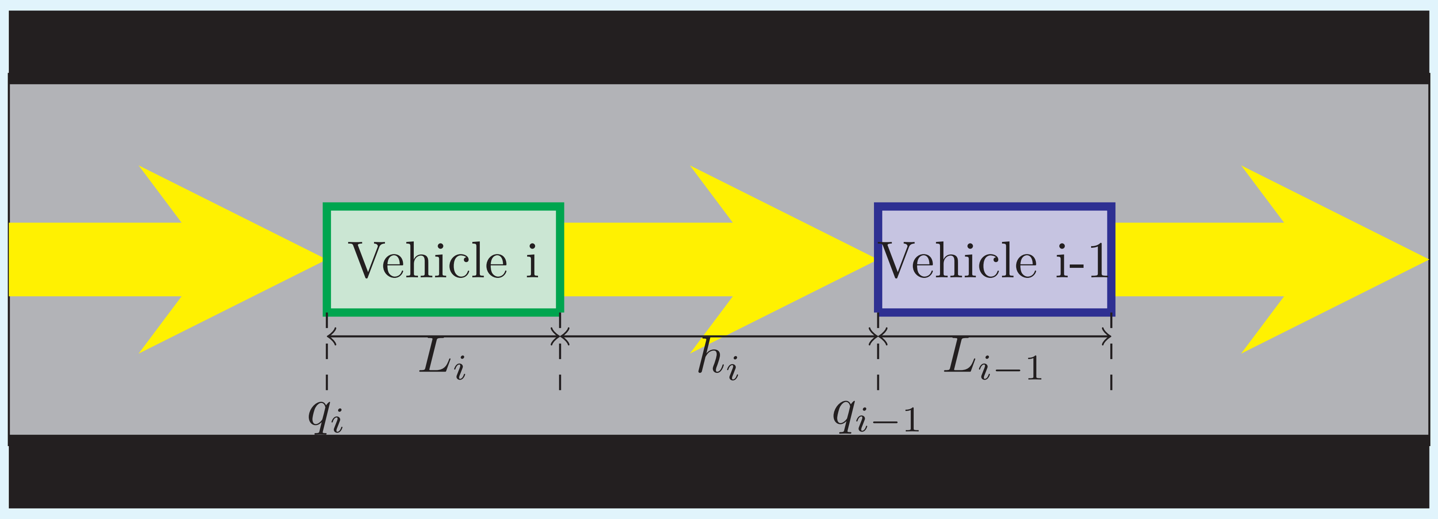
1. Introduction

This project consists, on the one hand, of using MATLAB and Simulink to simulate the behaviour of many human driven vehicles in a track; on the other hand, of taking advantage of Control Theory to design a control for autonomous vehicles that will be embedded among those human driven vehicles. The ultimate objective is to observe an improvement of traffic flow when autonomous vehicles are inserted.

2. Dynamics of vehicles

The model assumed for vehicles which travel in a single lane is stated next. Consider h as the net bumper-to-bumper distance, $v = \dot{q}$ as the speed and $a = \dot{v}$ as the acceleration. Also, τ_i is a time constant and F is a function which represents the acceleration demand, which can be given either by a model of human driving or by a control designed for an autonomous vehicle.

$$\begin{aligned} \dot{h}_i &= v_{i-1} - v_i \\ \dot{v}_i &= a_i \\ \tau_i \dot{a}_i &= -a_i + F_i\left(h_j, v_j, a_j\right) \end{aligned}$$



3. Human driving models

The first model to be considered is the MITSIM model.

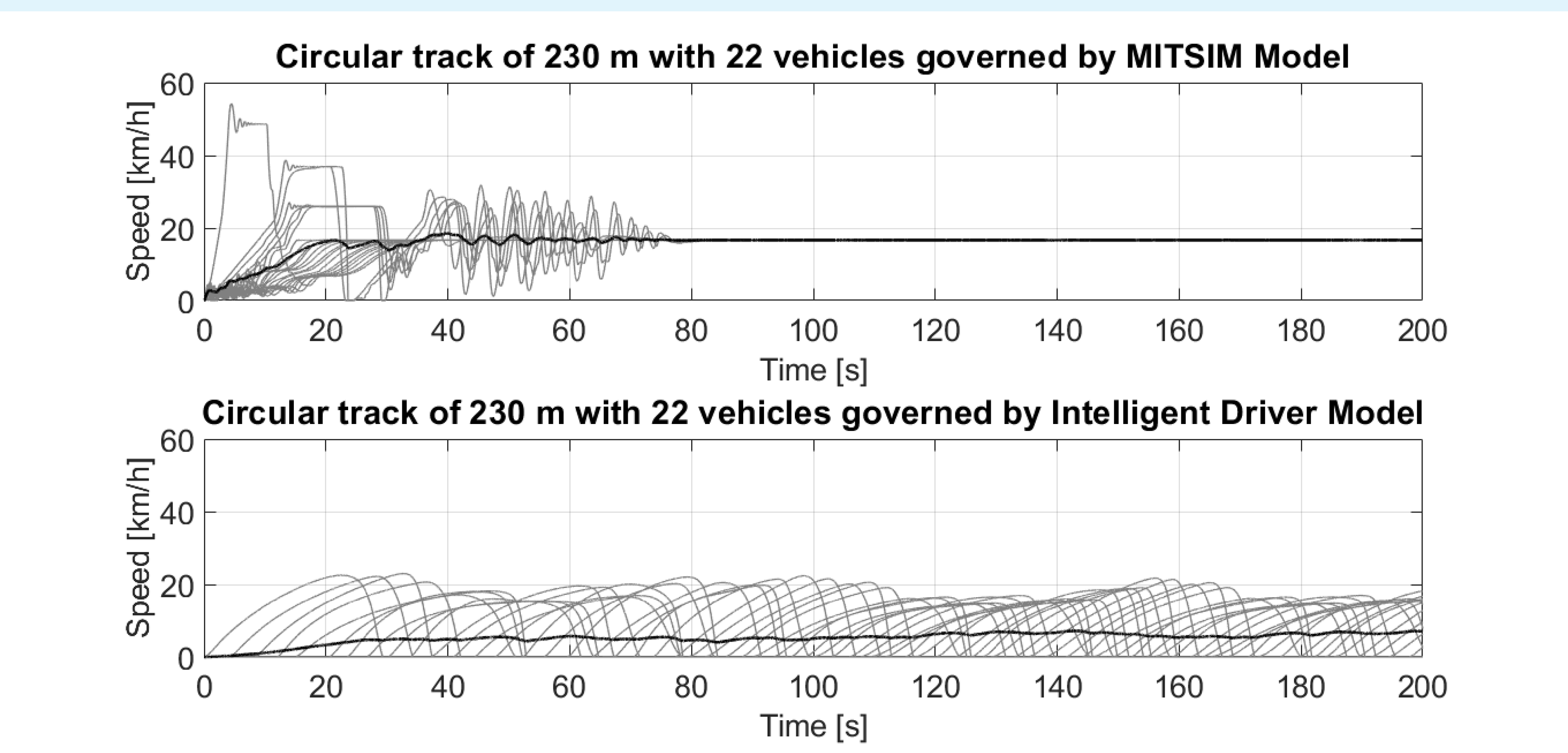
$$F_i^{MIT-CF} = \begin{cases} \alpha^+ \frac{(v_i)^{\beta^+}}{(h_i)^{\gamma^+}} \left(v_{i-1} - v_i\right) & \text{if } v_i \le v_{i-1} \\ \alpha^- \frac{(v_i)^{\beta^-}}{(h_i)^{\gamma^-}} \left(v_{i-1} - v_i\right) & \text{if } v_i > v_{i-1} \end{cases}$$

$$F_i^{MIT-FD} = \begin{cases} a_i^+ & \text{if } v_i < v_i^0 \\ 0 & \text{if } v_i = v_i^0 \\ a_i^- & \text{if } v_i > v_i^0 \end{cases}$$

$$F_i^{MIT-EB} = \begin{cases} \min\left(a_i^-, a_{i-1} - \frac{0.5(v_i - v_{i-1})^2}{h_i}\right) & \text{if } v_i > v_{i-1} \\ \min\left(a_i^-, a_{i-1} + 0.25 a_i^-\right) & \text{if } v_i \le v_{i-1} \end{cases}$$

The other model to be tested is the Intelligent Driver Model.

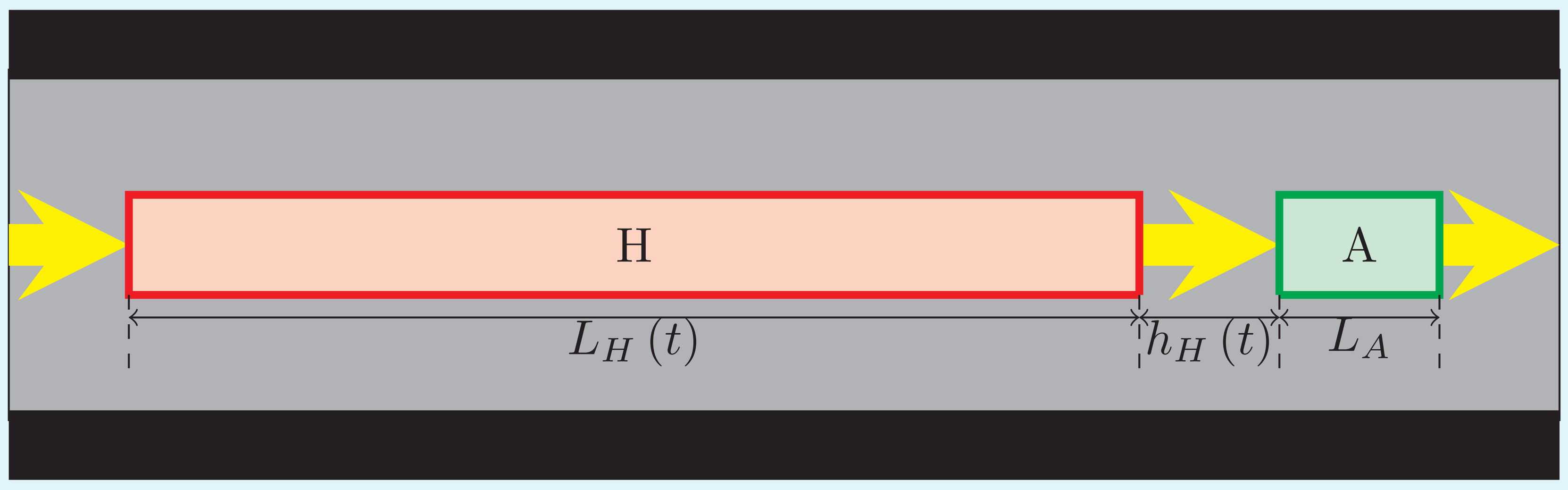
$$F_i^{IDM} = \begin{cases} a_i^{max}\left(1 - \left(\frac{v_i}{v_i^0}\right)^{\delta_i} - \left(\frac{h_i^0}{h_i}\right)^2\right) & \text{Regime 0} \\ a_i^{max}\left(1 - \left(\frac{v_i}{v_i^0}\right)^{\delta_i} - \left(\frac{h_i^0 + v_i T_i + \frac{v_i(v_i - v_{i-1})}{2\sqrt{a_i^{max} b_i^{max}}}}{h_i}\right)^2\right) & \text{Regime 1} \end{cases}$$



The model that represents better the behaviour of human driving is the IDM model. It is also simpler in terms of analysis.

4. Control design for autonomous vehicles

The first step for designing a control is to take a simplified problem. This primary setup will consist of an autonomous vehicle leading and a fleet of human driven vehicles chasing. The fleet of human driven vehicles is considered to have a length proportional to its speed.



$$\begin{aligned} \dot{h}_H &= v_A - v_H - \eta_H a_H \\ \dot{v}_H &= a_H \\ \dot{a}_H &= -\tfrac{1}{\tau_H} a_H + \tfrac{1}{\tau_H} F_H^{IDM}\left(h_H, v_H, v_A\right) \\ \dot{v}_A &= a_A \\ \dot{a}_A &= -\tfrac{1}{\tau_A} a_A + \tfrac{1}{\tau_A} u, \end{aligned}$$

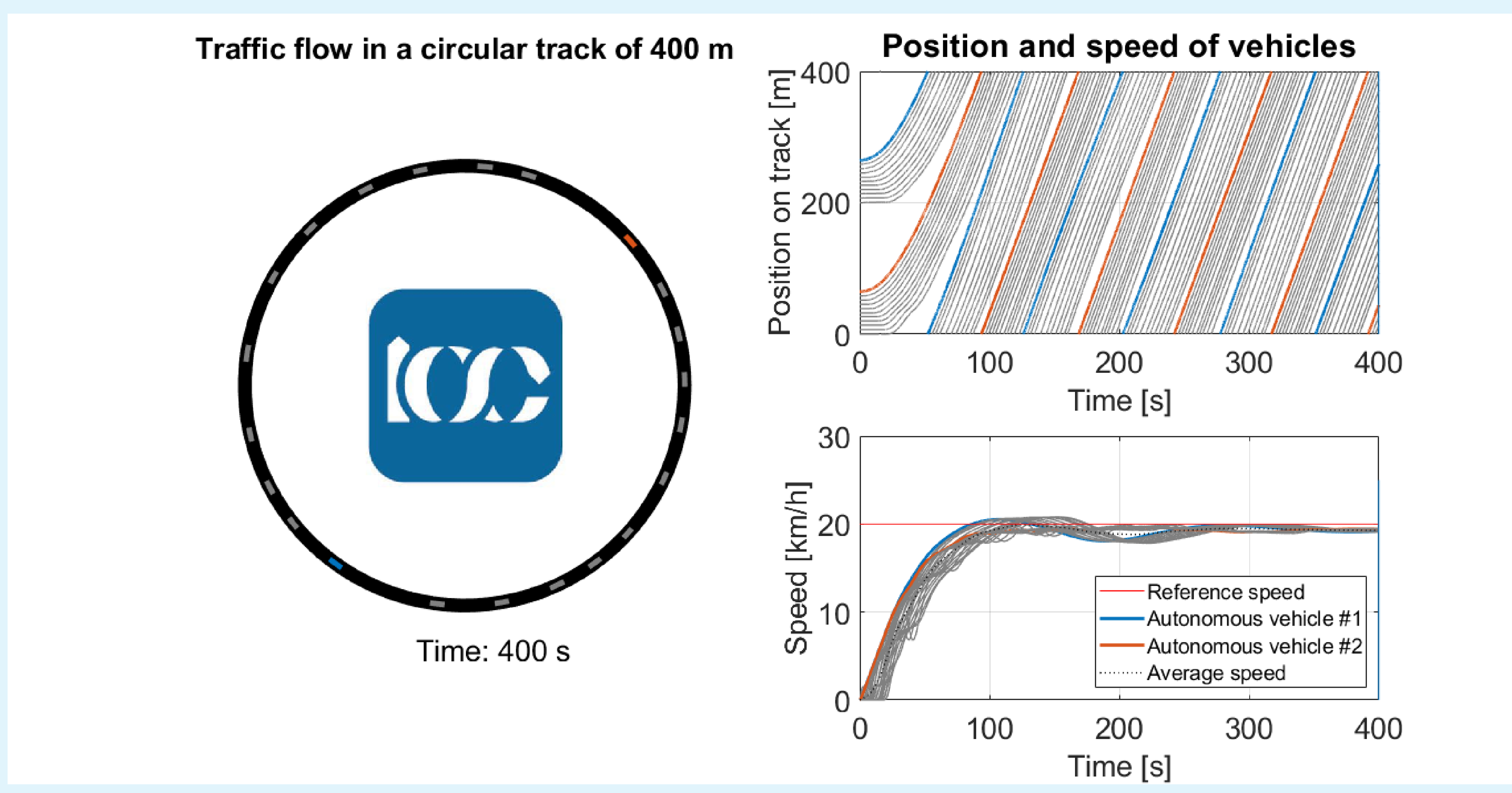
where the subscripts H and A refer to human driven fleet with variable length and autonomous vehicle, respectively. A control u will be applied to the acceleration of the autonomous vehicle a_A. It can be chosen to be a full state feedback controller with integral action or an output feedback proportional.

$$\begin{aligned} u &= -k_1 h_H - k_2 v_H - k_3 a_H - k_4 v_A - k_5 a_A - k_z z \\ \dot{z} &= v_H - v_r; \\ u &= k\left(v_r - v_H\right), \end{aligned}$$

where z accounts for the integral action and v_r is the reference speed towards which v_H is expected to tend.

5. Results

Two autonomous vehicles with the controller developed in Section 4 are embedded in a circular track among two fleets of human driven vehicles which are governed by IDM.



The stop and go effect is clearly reduced when autonomous vehicles take part.

6. Conclusions

Conclusions of this project can be summarized as follows:

1. Intelligent Driver Model fits the behaviour of human drivers and features the so-called stop and go effect.
2. Autonomous vehicles can be equipped with a control, where communication between two autonomous vehicles favours traffic flow.