A new linear platoon model based on reactive multi-agent systems

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***Abstract*—This paper presents a reactive multi agent approach to the platoon control problem for the linear configuration. Platoon is a train of vehicles composed of a head vehicle and a variable number of followers. Vehicle-to vehicle coupling is virtual. Each follower vehicle controls its movement by interacting only with the preceding one. To this end, platoon control was designed as a reactive multi agent system where each follower vehicle is an agent. Each agent behavior is specified by a physics inspired interaction model, which allows to compute vehicle speed and direction from a single perception: the distance to the preceding vehicle. We present the physics inspired interaction model together with a safety verification case study and simulations results.**

***Keywords*-Vehicle platoons; reactive agents; physics-inspired interaction model; verification; simulation.**

I. Introduction

Linear vehicle platoons are a promising approach to new transportation systems, with innovative capabilities, such as vehicle sharing and adaptability to demand. A linear platoon is a set of vehicles which circulate while keeping a train configuration without any vehicle-to-vehicle material coupling. The goals of each vehicle are, on one hand to be able to control braking and acceleration in order to stabilize the inter-vehicle distance, this is called **Longitudinal control**. On the other hand, to control the vehicle's direction in order to achieve single trajectory matching, this is called **Lateral control**.

All the Platoon approaches can be classified as global or local. Global ones require the presence of a decision making entity, generally embedded in the head vehicle, like in [4]. Global approach presents a good trajectory matching but suffers from the expensive technologies requirement.

In local approaches, each vehicle computes its own command references (acceleration and direction), and depends only from its own perceptions. Most of the lateral or longitudinal control strategies proposed within local approaches use PID controllers [2]. Other proposed approaches base on a physics-inspired, intervehicular interaction link from which vehicle's control references can be computed, as in [5]. Local approach does not require any expensive technologies, but it suffers from an anticipation error that can be partially resolved as in [1]. The goal of this paper is to improve this local approaches using a physical function wich has parameters that varies in relqtion with variation of the distance vector between two vehicles.

Additionally, we consider here the verification aspect. As a matter of fact, the acceptance of local approaches based on reactive multi agent systems depends on the possibility of ascertaining that a set of safety properties are satisfied. Model-checking appears as a feasible, tool-supported method, for the verification of safety properties.

In this work, we also present a verification case study, applied to our platoon control approach. The verified safety property is non collision in a standard functioning mode platoon.

This paper is structured as follow : section II mentions the coherence between the platoon system and the reactive multi-agent model, section III details the proposed physical inspired model, section IV develops the formal verification and the used tool. Finally section V draws some simulation results.

II. Multiagent system in linear vehicle platoon

The platoon multi-agent system proposed in this paper is a set of agents, each one corresponding to a vehicle in the train. Each agent is characterized by a set of parameters like an index within the platoon, a mass ... Two agent roles can be distinguished: the leader vehicle and the follower vehicle. Leader vehicle interacts directly with the road and follows a given trajectory. Follower vehicle role consists in interacting with the preceding vehicle in the platoon.

The behavior of each follower vehicle is determined from a physics inspired model. Agent global behavior is the result of the cyclic composition of three sub behaviors: **Perception** : Measures the inter-vehicle distance. **Control** : Computes the system acceleration. **PhysicalModel** : Computes the reaction as a function of dynamic characteristic and speed.

III. Physical model

The link between two following vehicles is virtual, it is made by a physics inspired interaction model composed of two springs and a damper like shown in figure 1.

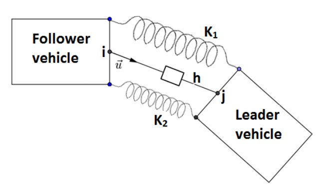

Figure 1. Physical interaction model in a turning case

Model parameters are stiffness of both springs k_1 and k_2, damping h and spring's resting length l_v.

Three forces are involved in this model :

- **Forces of both springs:**$\vec{F_i} = k_i(d_i \vec{-} l_v)$. Where $i \in \{1, 2\}$ and d_i is the Length of the first or second spring.
- **Force of Damper:**$\vec{F_d} = h(||\frac{\vec{\Delta D}}{\Delta t}||)$. Where D is the length of the damper.

Two calculations has to be performed. Firstly, the stiffness parameter value of each spring, in order to compensate the anticipation error by adjusting this values. Secondly, an interaction force that leads to the computation of an acceleration command reference. To calculate these unknowns, Newton law of motion is used : sum of forces law and the sum of moment of inertia law. Adding to this a criterion of a constant global stiffness. Acceleration and the two spring stiffness can be computed. By discrete integration, speed and vehicle state (position and orientation) can also be deduced.

IV. Model verification

In this work we present a simple verification case-study, about a safety property of the platoon MAS: non-collision of a follower vehicle with the leader vehicle during platoon operation with constant speed. We adopted the SAL bounded-model-checker (bmc) toolkit as modeling and verification framework, because it can be applied to system models that include real variables. The presence of real variables induces infinite (and even non-enumerable) state spaces, introduces the possibility of systematic non-termination and requires specific model-checking algorithms. SAL bmc uses Yices, an SMT (Satisfiability Modulo Theories) solver that decides the satisfiability of arbitrary formulas. Yices partially avoids the non-termination problem by a mechanism of k-induction, where k is an integer representing an exploration depth. The induction mechanism, of course, is not guaranteed to terminate in all cases, but avoids systematic non-termination.
The validity of the safety condition (The non-collision between vehicles) has been verified by the model checker.

V. Simulation

To test the model proposed above, the VIVUS1 simulator [3] developed by Set laboratory was used. To evaluate the quality of this platoon control approach, following tests are considered.

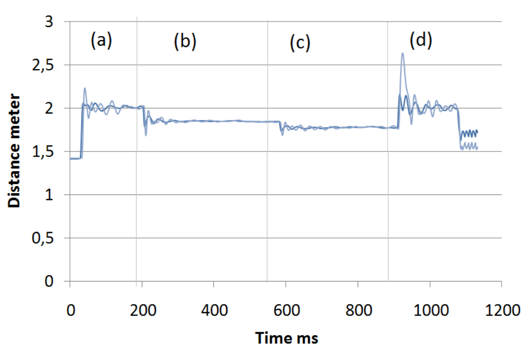

Figure 2. Inter-vehicle distance evaluation

Inter-vehicle distance evaluation : Consists of measuring distance between two following vehicles. In order to avoid collision between following vehicles, this distance should always be above a security distance (0.5 m). Figure V shows the result of this test. Inter-vehicle distance is measured in critical cases like quick acceleration (zone (a)), quick deceleration (zone (b) and (c)) and sudden braking (zone (d)). It is clear that inter-vehicle distance is always above the security distance.
Lateral error evaluation : Consists of measuring the trajectory matching between two successive vehicle. Figure 3 shows vehicles trajectory during a station exit. To exit the station vehicle must turn right then turn left. Maximal lateral error is found at the inflection point between the two bends. Figure 3 exhibits that maximal error is 0.5 m.

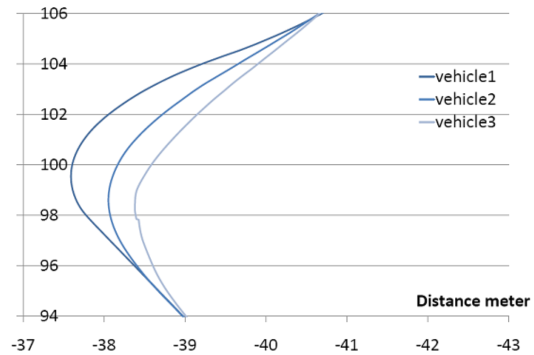

Figure 3. Trajectory error during the station exit

VI. Conclusion

The platoon system presented in this paper has been designed as a reactive multi agent system. Vehicles are autonomous entities in mutual interaction. Each vehicle is thus represented by a reactive agent, the behavior of which is computed from agent-environment and agent-agent interactions and perceptions. Each one interacts using laws inspired by physics. The developed solution is able to deal with both longitudinal and lateral control. This approach emphasizes interesting aspects of using physics inspired model with multi agent system. Firstly, all model parameters can be computed. Secondly, the emergent phenomenon is steady platoon motion. Simulation has allowed to measure some indicators of the emergent platoon organization. Additionally, verification aspect is considered by using Model-checking to verify the safety property : non-collision between vehicles. On this aspect, we are now working on the methodological aspects of verification applied to reactive MAS, by considering compositional verification approaches. Relatively to the platoon organization, we are now adding merge and split capabilities and studying other physics-inspired interaction models adapted to other platoon's geometric configurations.

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