Physics inspired multiagent system for vehicle platooning

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ABSTRACT

Since about two decades, many works have been made in order to provide solutions to the vehicle platoon problem. The main issue related to platoon systems consists in controling the global platoon geometry: inter vehicular distance and trajectory matching. Another important aspect is related to platoon's evolution, mainly by vehicle merging and splitting. This paper presents a reactive multiagent solution aimed at providing distributed control of vehicle platoons with train configuration. This solution is based on a physics inspired interaction model in which every vehicle interacts only with the preceding one. Platoon stability emerges as a global result of the individual interactions. Furthermore, the adaptation to different kind of vehicles is made by tuning model's physical parameters. Simulation experiments have been made in order to compare our proposal with impedance control model. The experiments have been designed in order to evaluate trajectory matching abilities and merge/split capabilities. Experiments with on-wheels small-robots have also contributed to the validation of our approach.

Categories and Subject Descriptors

I.2 [**ARTIFICIAL INTELLIGENCE**]: Distributed Artificial Intelligence—*Multiagent systems*

General Terms

Experimentation

Keywords

Platoon, reactive multi-agent, longitudinal and lateral control, merge and split, physics inspired behavior model.

1. INTRODUCTION

Since two decades, many works have been made in order to cope with the platoon issue [2]. Platoon systems can be defined as sets of vehicles that use local perception abilities to form train or well-defined structured formations. Virtual train platoon systems can be divided into three main subproblems: longitudinal control, lateral control and merge and split. **Longitudinal control** consists in controling braking and acceleration in order to stabilize the distance between the leader vehicle and the followers. *Sheikholeslam and Desoer* [4] proposed longitudinal control using linearization methods. *Ioannou and Xu* [3] controlled the brakes and acceleration by fixed gain PID control (Proportional, Integral, Derivative) with gain scheduling. **Lateral control** consists in aligning the vehicle direction in relation to preceding one. *Soo-yeong Yi and Kil-to Chong* [5] represented immaterial fixing with impedance control model. As for merge and split abilities, they are generally treated as simple line changing [1]. The main interests of the use of multiagent systems, and especially reactive systems, in such applications are the intrinsic properties : adaptativity, robustness and reliability. This paper presents a platoon systems based on a physics inspired reactive multiagent system. The developed solution is able to deal with both longitudinal and lateral control using Newtonian forces as interaction model. Moreover, our system has merge ans split capabilities. The paper is structured as follow. The first part describes the formal model used for the proposed multiagent platoon system using the statecharts formalism. Second, the interaction model is defined based on Newtonian physics. Then, merge and split abilities are detailed. Finally, experimental results on both simulation and real robots experimentation are exposed.

2. THE MULTIAGENT MODEL

2.1 Agent's description

The platoon multiagent system developed in this paper is composed of a set of agents each corresponding to a vehicle in the train. Each agent is characterized by parameters such as mass (expressed in kg), index in the platoon (0 is given to the head) and weighting depending on its position in the train.

2.2 Roles and interactions

Each agent of the system has a specific role on which depend its behaviors and the interaction to be applied. Thus, a role can be considered as a set of abstract behaviors, each characterized by a set of interactions. The two main roles

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are the following : the **vehicle** role which deals with each element of the platoon independently and the **platoon** role which deals with the behaviors of the whole train. For the vehicle role, two different sub-roles have been defined : the header vehicle and the follower vehicle. The header vehicle interacts directly with the road or follows a determined trajectory. The follower vehicle role consists in interacting with only the preceding one in the platoon. These interactions are mostly based on the visual perception. However, communication between vehicles can be used instead. Platoon role consists in communication supervising between each vehicle.

2.3 Agent's Behavior

In order to describe the formal model and specification of agent behaviors, we use the statechart formalism.

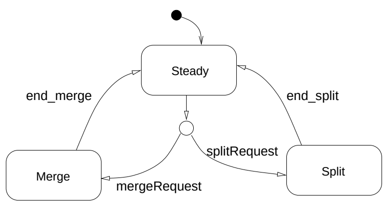

Figure 1: Platoon agent behavior

Figure 1 presents one of the two vehicle platoon roles. Platoon vehicle role is composed of two states: Merging and Splitting. These two states represent the merging phase of one external vehicle into the platoon system on the one hand and the splitting phase of one inside platoon system vehicle on the other. The events mergeRequest or splitRequest activate the splitting or merging state.

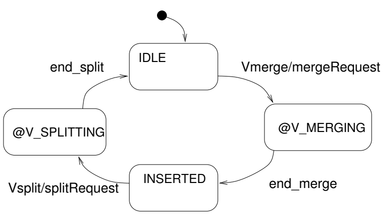

Figure 2: Vehicle agent behavior

Figure 2 shows the vehicle role possibilities. A vehicle can merge with or split from the platoon. Merge behavior start when vehicle receives the event VMERGE which can be sent by a station or person call. Then an event is sent to the platoon thus starting the merge phase. Split phase differ from the previous thanks to the nature of the received message : VSPLIT. When a vehicle wants to split or merge with the platoon system, it can be considered at two different levels: individual vehicle level and platoon level.

The merge phase (Figure 3,left) combines concurrently the merging behavior of the merging vehicle and of the platoon. As for the vehicle point of view, merging starts with the detection of the last vehicle in the platoon. Then, if the mergecondition is filled, vehicle merge ends and platoon merge starts. The platoon merge statechart consists in, first, waiting for the end event of the vehicle statechart. Then, in the REG state a new weighting of each agent is computed and sent in broadcast to every platoon members. This new weighting corresponds to the new index of each agent.

Split phase 3 (right) consists in the same partition as merge phase (vehicle level and platoon level).

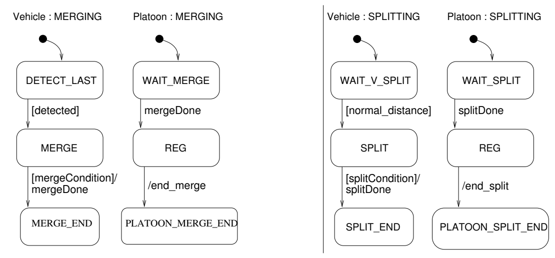

Figure 3: MERGING sub-roles (left) and SPLITTING sub-roles (right)

3. INTERACTION BETWEEN A VEHICLES

3.1 Interaction model

The link between two vehicles is made up by a physics inspired model. This virtual connection between each vehicle is formulated as a standard Newtonian force in $1/r^2$. Besides other forces have been added to take into account real vehicle environment. The forces applied to each in platoon vehicle are the following: (i) Newton attraction force between one vehicle and its preceding $\vec{F_n}$ (β is a gravitational-like constant), (ii) Amortiguation force f_a, (iii) Fluid friction force F_f (λ is the environment friction parameter). Each vehicle i is represented by its position $\vec{X_i} = [x_i, y_i]$. Vehicle mass is denoted m_i. The distance between vehicles is computed by $d = \|\vec{X_i} - \vec{X}_{i-1}\|$.

The forces involved are thus :

- Newton force : $\vec{F_n} = m_i * m_{i-1} * \beta * \frac{\vec{X}_i - \vec{X}_{i-1}}{\|\vec{X}_i - \vec{X}_{i-1}\|^3}$
- Amortiguation force : $\vec{F_a} = -\xi(\dot{\vec{X_i}} - \dot{\vec{X}}_{i-1})$
- Fluid friction force : $\vec{F_f} = -\lambda \dot{\vec{X_i}}$

The acceleration value can be computed considering newton equation. By discrete integration, we can then determine speed and vehicle state (position and orientation).

3.2 Model parameters

This model is based on six variables, mass m, gravitational-like constant β, fluid friction parameter λ, Amortiguation parameter ξ, safety stop distance D_S and good following distance D_{nd}. All model parameters could be defined. As opposed to most system where parameters have to be tuned manually or empiricaly, vehicle attribute values can be changed thanks to inter-agent communication.

4. VEHICLE MERGING AND SPLITTING

The model presented in this article include merge and split capabilities. The merging phase (figure 3,left) results in a new vehicle being added at the end of train. The merging vehicle is initially parked and waits for the train. When the merge vehicle detects the last platoon vehicle, it follows it by applying the impedance control model. If the merging vehicle is close enough to the last train vehicle, it sends a message to the preceding vehicle with new weighting and index. Split phase (figure 3, right) is similar.

5. EXPERIMENTAL RESULTS

Experiments have been performed both by simulation and use of real small robots that have similar dynamical characteristics compared to real vehicles. As for the simulation, results has been compared to those obtain with a classical approach based on an impedance control model [5].

5.1 Simulation results

5.1.1 A reference model

The reference model used is presented in details in [5]. In this model, the link between two vehicles is modeled by an impedance control composed of a damper and a spring. For each vehicle agent, perception is composed of an estimation of relative position of preceding-vehicle and following vehicle.

5.1.2 Computer simulation with the Madkit platform

The model described in the previous section has been implemented thanks to Madkit multi-agent platform [1] proposed by *J. Ferber* and *O. Guknecht* Computer simulations are used to validate some model characteristics. The simulation runs with a platoon of 4 following vehicles. The first vehicle follows a preset trajectory : a square with rounded cornes. Experiments have shows that our model is more flexibility and adaptability(cf figure 4).

	Our model	Impedance control model
Regular trajectory error	1.5 m	5 m
Inter vehicle distance	no residual variation	residual variation 3% safety length
Obstacle avoidance	possible	impossible

Figure 4: Computer simulation : our model and impedance control model

5.2 Real experiments with the robosoccer platform

Experiments have been made to test the controller model under real-world conditions. Theses real experiments have been done with a robosoccer platform. As for the real vehicle, small 2-wheel drive Mirosot6 [2] soccer robots have been used. These robots move on a playground and controlled by a standard PC computer that sends data to each robot through a RF interface. The perception is performed by a CCD camera placed above the playground.

These experiments has checked the model flexibility and adaptability. A platoon system with three vehicles was simulated. As in the previous experiments, the first vehicle follows a preset trajectory. Experiments base on a platoon system with two following vehicles. The average errors can be scaled up from robot size to real vehicle size. The error value is 2 m compares to the 2 m length of the vehicle.

[1]Madkit5, http://www.madkit.org

[2]http://www.merlinrobotics.co.uk/merlinrobotics/

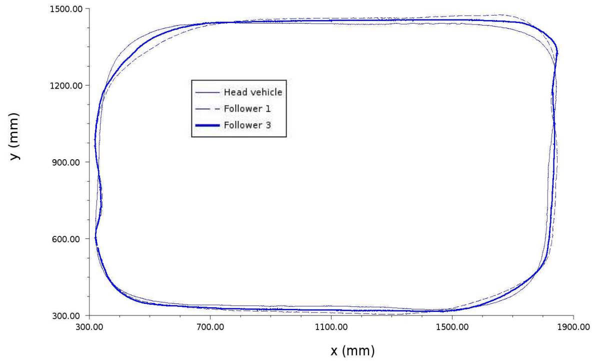

Figure 5: Experimentation with 3 robots

6. CONCLUSION

The platooning system presented in this paper is based on a reactive multiagent 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. Each uses laws inspired by physics. The developed solution is able to deal with both longitudinal and lateral control. Moreover, we add merge and split abilities to our system. This model keep interesting points of physics inspired and multiagent system. On the one hand all model parameters could be defined simplify and rapidly thanks to to any vehicle as opposed to classical model. On the other hand, the emergent phenomenon is a steady platoon motion with vehicle merging and splitting abilities. Multiagent simulation has demonstrated the essential characteristics of this kind of solving method: Flexibility/Adaptability (linking and avoidance capabilities) and Reliability (low error rate in curve and damping time). Moreover a comparison with the *Soo-yeong Yi and Kil-to Chong*[5] multiagent model has been made. The difference with a classical physics inspired model consists in the fact that we take into account only a local point of view. For each vehicle agent, perception is limited to an estimation of relative position of preceding-vehicle.

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