Application of reactive multiagent system to linear vehicle platoon

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Abstract

Vehicular platoon are a promising approach to new transportation systems, with innovative capabilities, such as vehicle sharing and adaptability to demand. This paper presents a multiagent solution to the platoon control problem with a linear configuration. In our case, a platoon is a vehicle train composed of a head vehicle and a variable number of followers. The head vehicle is human-driven or autonomous, whereas each follower vehicle controls its movement by interacting only with the preceding one. To this end, the platoon control system was designed as a reactive multiagent system where each follower vehicle is an agent. Each agent's behavior is specified by a physics inspired model, which allows to compute vehicle's speed and direction from a single perception: the distance to the preceding vehicle. Platoon stability emerges as a global result of individual interactions. Furthermore, adaptability to different kinds of vehicles is obtained by adjusting the model's physical parameters. Another important aspect is related to platoon's evolution, mainly by vehicle merging and splitting. To assert the transition from abstract to concrete, both simulations and experimentations have been implemented.

1 Introduction

Vehicle platoon systems are a promising approach to new transportation systems [6], with innovative capabilities. Their main goals, when applied to civil cars, are: (i) an increase of the vehicle density in highway (i.e. avoiding traffic jam), (ii) a security improvement in car travel thanks to automated or semi-automated driving assistance (adaptive cruise control, obstacle detection and avoidance, automatic car parking,...). Vehicle platoon control can be divided into three main sub-problems: longitudinal control, lateral control and merge and split capabilities. Longitudinal control consists in controling braking and acceleration in order to stabilize the distance between the leader vehicle and the follower [7]. Lateral control consists in aligning the vehicle direction in relation to preceding vehicle [3]. In order to model vehicle platoon system with longitudinal and lateral control, *Soo-yeong Yi and Kil-to Chong* [8] represent immaterial fixing with impedance control model. *Simon Halle* uses MultiAgent System (MAS) in order to model immaterial vehicles fixing using constant values from [3]. As for merge and split abilities, they are generally dealed as simple line changing transitions[5]. The main interests of the use of multiagent systems, and especially reactive systems, in such applications are the intrinsic properties they can bring. Their application to a wide range of fields (life-systems simulation/study, cooperation/coordination of situated vehicles/agents, data fusion [4],...) shows relevant properties such as adaptivity, robustness and reliability. A physics inspired reactive multiagent model of platoon system has already been proposed [1], with spring damping forces as interaction model. In this paper the developed solution is able to deal with both longitudinal and lateral control using Newtonian forces as interaction model. This proposal also includes merge and split capabilities. The paper is structured as follow. The first part describes the formal model used for the proposed multiagent platoon system. Second, the interaction model based on Newtonian physics is presented. Then, merge and split abilities are detailed. Finally, experimental results on both simulation and with real robots as vehicles are exposed. The paper finishes with a conclusion and a presentation of future work.

2 The Multiagent formal model

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 a set of attributes such as index in the platoon and the mass. In order to describe the formal model and specification of agent behaviors, we use the statechart formalism. This formal model is defined more precisely in [2]. Here the most important role have only been presented. Each agent is assigned to a specific role which can be considered as a set of abstract behaviors, each one being characterized by a set of interactions. The two main roles are the following: vehicle role which deals with each element of the platoon independently and platoon role which deals with the behaviors of the whole train. Whereas the follower vehicle role consists in interacting with only the preceding one in the platoon, the head vehicle interacts directly with the road or follows a computed trajectory. These interactions are mostly based on visual perception.

3 Interaction between two vehicles

3.1 Interaction model

The link between two vehicles is made by a physics inspired model. This virtual connection between each vehicle is formulated as a standard Newtonian force in $\frac{1}{d^2}$. Other forces have been added to take into account the dynamics and the real vehicle environment. The forces applied to each in platoon vehicle are the following: (i) Newtonian attraction force between the front vehicle and its preceding $\vec{F_n}$ (β is a gravitational constant), (ii) Damping force $\vec{F_d}$, (iii) Fluid friction force $\vec{F_f}$ with λ the environment friction parameter. Figure 1 shows a 3-vehicle part of the considering platoon. Each vehicle i is represented by its position $\vec{X_i}$ = $[x_i,y_i]$ and its speed $\dot{\vec{X}}_{i-1}$. Vehicle mass is denoted m_i. The distance between vehicles is computed $d = \|\vec{X}_i - \vec{X}_{i-1}\|$.

The forces involved are thus :

- Newton force : $\vec{F}_n = m_i * m_{i-1} * \beta * \frac{\vec{X}_i - \vec{X}_{i-1}}{\|\vec{X}_i - \vec{X}_{i-1}\|^3}$
- Damping force : $\vec{F}_d = -\xi(\dot{\vec{X}}_i - \dot{\vec{X}}_{i-1})$
- Fluid friction force : $\vec{F}_f = -\lambda \dot{\vec{X}}_i$

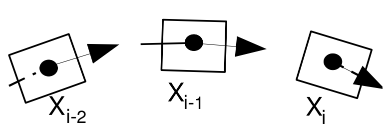

Figure 1. Part of the platoon centered around vehicle $i-1$.

From the Newton's law of motion, we could deduce the difference equation.

$$m_i * \vec{\gamma} = m_i * m_{i-1} * \beta * \frac{1}{d^2} * \frac{\vec{X}_i - \vec{X}_{i-1}}{\|\vec{X}_i - \vec{X}_{i-1}\|} - \lambda \dot{\vec{X}}_i - \xi(\dot{\vec{X}}_i - \dot{\vec{X}}_i) \quad (1)$$

Acceleration value can be computed considering equation (1). By discrete integration, we can determine speed and vehicle state (position and orientation). Then the command law can be computed. In our case, it consists in vehicle direction and speed[1]. The physics inspired model is used to specify MAS. Each vehicle is represented by a reactive agent. The behavior of a reactive vehicle agent is computed from agent-environment and agent-agent interactions and perceptions. For each vehicle agent, perception is limited to an estimation of relative position of preceding-vehicle. Action is decided using only this perception.

3.2 Model parameters

This model is based on six parameters: mass m, gravitational constant β, fluid friction parameter λ, damping parameter ξ, safety stop distance D_S and regular following distance D_{nd}. All model parameters can be computed thanks to the differenial equation (1), as opposed to most system where parameters have to be tuned manually or empirically.

4 Vehicle merging and splitting

The model presented in this article include merge and split capabilities. It has been implemented on the base of a MAS architecture. The merge phase consist in adding a vehicle at the end of the platoon. The merging vehicle waits for the last vehicle of the platoon and follows it. The merging vehicle controls the insertion process based on the Newtonian force model. When the distance between the two last vehicles is equal to the regular distance the last vehicle sends new weighting and index to signal the end of merging phase. Whereas the split phase is described as follow: any vehicle could split from the train. If a vehicle wants to split, new weighting and index are sent to the following and the preceding ones. When the distance between the splitting vehicle position and it destination is equal to a predefinied split distance the vehicle split from the train. In this case the Newton model is applied with the distance to the destination as parameter.

5 Experimental results

Experiments have been performed on both simulation and with real robots that have similar dynamical characteristics as real vehicles. As for the simulation, results have been compared to those obtained with a reference approach based on impedance control model [8].

[1]The choice of a command law takes into account the characteristics of the test vehicle used in our laboratory

5.1 Simulations results

5.1.1 A reference model

The reference model used is presented in details in [8]. In this model, the link between two vehicles is performed by an impedance control model composed of a damper and a spring. It is important to note that this reference model takes into account a global (not local) point of view: each vehicle agent's perception is composed of an estimation relative position with preceding and following vehicle.

5.1.2 Computer simulation with the Madkit platform

The model described in the previous section has been implemented thanks to the multiagent platform [2] proposed by *J. Ferber* and *O. Guknecht*. The simulation runs with a platoon of 4 following vehicles. The first vehicle follows a preset trajectory: a square with maximal angles of 90 degree. The simulation of rectilinear trajectories has shown that the following errors (i.e. disparity in the distance between two successive vehicles) are below the millimeter for the two different models. Figures 2 illustrates platoon displacement arround a corner, displaying both the leader and follower trajectories. These figures exhibit an increase in trajectory error from one vehicle to its follower.

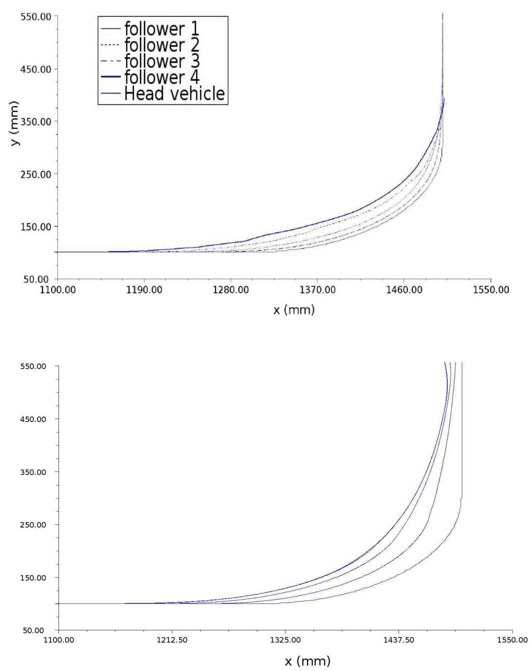

Figure 2. Computer simulation: Newton model(Top), impedance model(Down)

Both model show an increase in trajectory error from one vehicle to its follower. The Newton model error can be scaled up towards real vehicle length: 1.5 m compared to the 2 m length of a vehicle. On the other hand the impedance control model [8] error is more significant: 5 m. Moreover, with the Newton model the linear platoon configuration is restored within a short distance while the impedance control model needs much more time to recover stability.

Other simulations have been made :

- Obstacle avoidance : The leading platoon vehicle avoids an obstacle on the road: we have been test that all following vehicles also avoid this obstacle and preserve the platoon structure. However only the Newton model proposed an obstacle avoidance response with all vehicles dodging without trajectory instability (oscillations).
- The merging process was simulated in order to visualize the duration of the transitory phase of distance stabilization. The Newton simulation has shown that the merging time and the variance of inter-vehicle distance are less important than with the impedance control model.

5.2 Real experiments with the robot soccer platform

Experiments have been made to test the control model under real-world conditions. Theses experiments have been done on a robot soccer platform. Small 2-wheel drive Mirosot6 [3] soccer robots have been used. Robots are 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. A standard PC computer has been used to execute the MAS software.

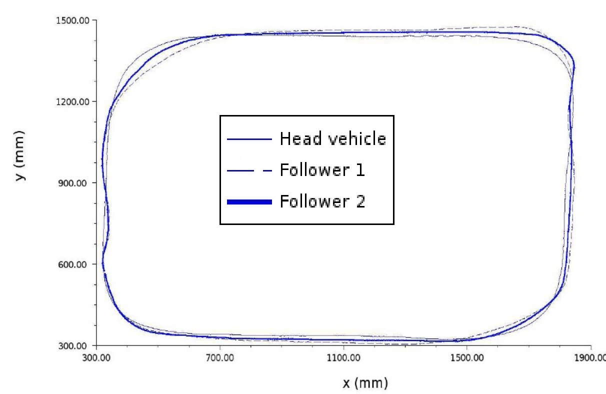

Figure 3. Experiment : Newton model

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

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

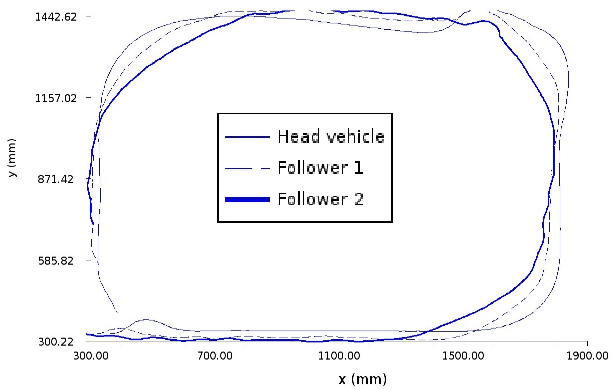

Figure 4. Experiment : impedance control model

Experiment based on a platoon system with three vehicles. As in simulations, the first vehicle follows a preset trajectory. Figure 3 and 4 shows the trajectories obtained with two following vehicles. The trajectory errors can be scaled up to the real vehicle size. The maximal curve error is 2 m with Newton model and 6 m with impedance model compared to the 10 m platoon length. The huge error with impedance control model is due to parameters value by rule of thumb and the globally computed trajectories. The probability of error is amplify because distance relative to both preceding and following vehicle must be estimated.

Conclusion of simulations:

	Our model	Impedance model
Regular trajectory error	1.5 m	5 m
Inter vehicle distance	no residual variation	residual variation 3% safety length
Obstacle avoidance	possible	impossible
Experimentation	2 m	6 m

Figure 5. Computer simulation : Newton model and impedance control model

6 Conclusion

The platooning system presented in this paper has been made by 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 and perceptions. Each one interacts using laws inspired by physics. The developed solution is able to deal with both longitudinal and lateral control. Moreover, we add merge and split capabilities to our system. This approach emphasises interesting aspects of using physics inspired model with multiagent system. Firstly, all model parameters can be computed, as opposed to most system where parameters have to be tuned manually or empirically. Secondly, the emergence phenomenon is a steady platoon motion with vehicle merging and splitting capabilities. Multiagent simulation has illustrated the essential characteristics of this kind of solving method: Adaptability (merge and split), reactivity (obstacle avoidance) and Reliability (low trajectory error and good stability). Moreover a comparison with the *Soo-yeong Yi and Kil-to Chong* multiagent model [8] 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. Then simulations have been made in order to compare our model with a classical physics inspired one. We are now running into further research on different critical points of the problem: we are studying other interaction models in order to compare them experimentally. We are also working on a proved implementation of our system, using the B formal method.

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