A Layered Multi-Agent Model for Multi-Configuration Platoon Control

Baudouin Dafflon, Franck Gechter, Pablo Gruer and Abderrafiaa Koukam
IRTES-SET, UTBM, Belfort, France

Keywords: Multi-Agent Model, Platoon Control.

Abstract: Nowadays, urban environments suffer from recurrent traffic jam with associated side effects. Platoon system, a set of vehicle attach by virtual link, is one of answer. in order to cope with issues such as different platoon geometrics since several years, we're seeing the multi-agent system as element of response to many problems. This paper to apply this concept for platoon vehicles system through an multi-agent model based on key layers. Thanks this solution, implemented as an agent which makes decisions depending only on its own perception where each vehicles is recorded, analysed, transform in car command and adapted to vehicle by a command filter.

1 INTRODUCTION

Platoons can be defined as a set of autonomous vehicles evolving on a particular environment while maintaining a particular geometric configuration. Platoon control consists in determining the behaviour of each one of the vehicles during platoon evolution, in order to maintain the configuration and adapt it to changes in the terrain (presence of unanticipated obstacles, decreasing of available surface, ...).
Several international projects, past or present, address platoon control. Among them, we can cite PATH (Hedrick et al., 1994), SARTRE (Chan et al., 2011), CRISTAL[1], SAFEPLATOON (Cartade et al., 2002) [2]. Most of them deal with column platoons as unique configuration and situate in well defined environment such as highways where the curve radius are high and where the speed can be considered to be constant most of the time. However, other application domains, placed in different kinds of environments could benefit from platoons composed of different types of vehicles. Among those application domains we can mension transportation and maintenance operations in urban areas, labouring and harvesting in agricultural areas and military operation theatres. Those cases are subject to diverse, more stringent constraints. As an example, in urban areas with a column configuration, the lateral error must be highly limited in order to avoid collisions. In echelon or line configurations, environment related constraints are more influential.

[1]http://projet-cristal.net/
[2]http://web.utbm.fr/safeplatoon

In this paper, we propose an multi-agent based approach for the multi-configuration platoon control problem. The approach can be considered as self-organizing, because platoon configuration emerges from the behaviour of each vehicle, strictly based on local vehicle's perceptions. The platoon's configuration is determined locally by assigning to any platoon vehicle another neighbouring platoon vehicle, considered as local leader. This proposal is structured as a multi-layer decision process dealing first with the interpretation of the perception data, then integrating the choice of the local leader depending on the intended spatial configuration and finally producing a kinematic decision that has to be performed by the vehicle. In this approach, each vehicle is considered as an agent which bases on its perceptions and on the local intended configuration to make the correct decision. The proposed approach integrates obstacle avoidance abilities which is based on a multi-agent filtering method similar as the one developed in (Franck Gechter and Koukam, 2010).
The paper is structured as follow: after a short reminder about vocabulary, a state of the art on platoon systems is proposed. Then, the multi agent system applied to platoon control is described. Finally, a conclusion and some considerations on future work directions are presented.

Dafflon B., Gechter F., Gruer P. and Koukam A. (2013).
A Layered Multi-Agent Model for Multi-Configuration Platoon Control.
In *Proceedings of the 10th International Conference on Informatics in Control, Automation and Robotics*, pages 33-40
DOI: 10.5220/0004632500330040

2 DEFINITIONS

The literature introduces a rich terminology in related to the platoon domain. In this section, we intend to present the vocabulary used along the work, in order to avoid ambiguities.

2.1 Leaders

Vehicles with a distinctive role within the platoon are frequently qualified as leaders. We distinguish two kind of leader roles.
Global Leader. The global leader is the reference vehicle of the entire platoon. It can be fully autonomous, applying a path-following algorithm, or driven by a human operator. The global leader determines the reference trajectory for the convoy. **Local Leader.** The local leader notion is tied to local, self-organizing approaches, and corresponds to the vehicle taken as a reference by a follower vehicle. Each vehicle in the platoon has a local leader, but this role can be assigned dynamically during platoon operation. Generally, the local leader is taken among the closest vehicles in the follower perception field.
Virtual Leader. The notion of virtual leader is tied to the mechanisms involved in our methods. The principle developed in this paper, is to be able to transform any spatial configuration into a local column configuration of a local leader and its follower, and to apply a well defined interaction model, to determine follower's behaviour.

2.2 Geometry

A platoon configuration geometry is defined by means of two distances, lateral and the longitudinal (cf. Fig.1). The **Lateral distance** represents the lateral spacing between two neighbour vehicles. The **Longitudinal Distance.** represents the spacing between two neighbour vehicles, in the direction of the move.

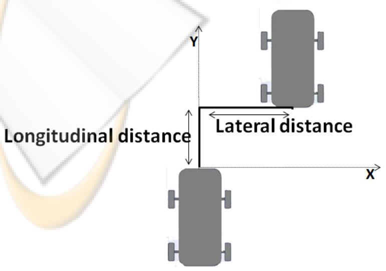

Figure 1: Lateral and longitudinal distances.

Configuring a platoon formation bases on the definition of both lateral and longitudinal distance. Depending on the values of these, several platoon configuration can then be defined, among which we can mention: **Column Configuration.** This configuration, represents the most frequently studied form of platoon where vehicles organize as train (cf.figure 2). In this configuration, lateral distance should remain as small as possible (for curved trajectories this means mono-trace displacement). Column configurations have been foreseen as mostly dedicated for the transport of passengers in urban or highway transportation systems.
Line Configuration. In this configuration, vehicles are placed side by side (cf.figure 2). The longitudinal distance must be null. This configuration can be applied to agricultural tasks, such as tilling.
Echelon Configuration. Vehicles are in an inclined column configuration, each is offset from the preceding by a lateral distance (cf.figure 2). In this configuration, lateral and longitudinal nominal distances have a specified, non null value. This configuration can be dedicated to agricultural or military applications.
Arbitrary Configuration and **Wedge Configuration.** Arbitrary configurations can hold many geometrical forms, produced by the combinations of two or three of the configurations described above. These configurations are mostly used in military environments. In wedge configuration for instance, leader vehicle is followed by echelons of vehicles placed to the right and the left forming an inverted "V" formation (cf. figure 2).

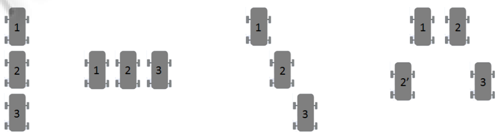

Figure 2: Configurations of platoon. From left to right: column, line, echelon, wedge.

3 STATE OF THE ART

Platoon control approaches can be sorted into two main categories: local approaches base on a local reference frame. On the other hand, global approaches base on a global frame, common to every vehicle in the platoon.

3.1 Local Approaches

Local approaches are based on a local reference frame which generally anchors in the follower vehicle. In this frame, the position and the orientation of the local leader can be determined in the local frame. Consequently, the local approach can be considered as the regulation of both lateral and longitudinal distances between the follower and its local leader.

Among the proposals corresponding to this approach, we can mention:

- System based on an automatic control mechanism: (Daviet and Parent, 1996) proposes a mechanism for local control based on a PID (Proportional, Integral, Derivative) controller . The measurement acquisition is performed by linear cameras or by a range finder sensor (Riess, 2000). The control reference is decomposed on one hand in a longitudinal reference and on the other hand in a lateral reference.
- Control based on undumped impedances: (Gehrig and Stein, 2001) presents a model of light links where vehicles are treated as particles subjected to physical forces.
- Control model based on a double impedance control: in (o Yeong Yi and Chong., 2005) an impedance control model is used as a model of the immaterial link between vehicles.
- Control based on a virtual mechanical link: In these approaches, each vehicle in the convoy is designed as an intelligent system able to perceive its environment and maintaining a pre-set distance with the preceding vehicle. The platoon system is the result of direct interaction between each vehicle and its predecessor. This approach is based on an interaction model inspired by the physics. Indeed, the interaction between two successive vehicles virtual link shown by a mass-spring type. Among these one can cite (Franck Gechter and Koukam, 2010).

3.2 Global Approaches

Each vehicle determines its control references depending on a global shared reference. Platoon trajectory is determined by the global leader and expressed as a series of trajectory points situated in the global reference frame, known by every vehicle. The sharing of the trajectory points implies vehicle to vehicle communication capabilities and high performance global localisation devices aimed at determining the position of each vehicle in the global reference frame. Platoon control can be considered as the regulation of both lateral and longitudinal distance between each vehicle and the reference trajectory.

Among the proposals corresponding to this approach, we can mention:

- An optimal controller is proposed in (Levine and Athans., 1966) to serve on a constant set of intervehicle distance in columns moving at high speed.
- In (Caicedo et al., 2003), the formation is characterized by a set of generalized coordinates describing the position and the orientation. The resulting shape and evolution of the column is based on the laws of mechanics.

Relatively to military platoons enumerated, these can fit the global/local classification. Unit center referenced and leader referenced approaches can be considered as global (the control can be centralized or decentralized). By contrast, Neighbour-referenced technique is local and decentralized.

4 MULTI LAYERS DECISION PROCESS

4.1 Global Overview

Our proposal is based on a multi-layer systems for decision making. This architecture provides a set of 5 plug and play units (cf. Fig 3). The principle developed is based on the transformation of any spatial configuration into a column configuration which uses a well defined interaction model. Then, we use a virtual leader, the position and the orientation of which correspond to the transformation of the local leader position and orientation taking into account platoon spatial desired configuration.

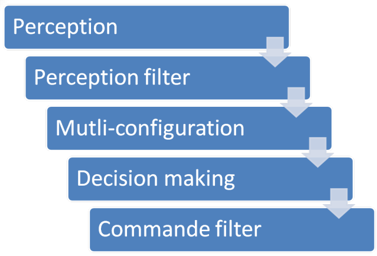

Figure 3: Multi-layer Architecture.

Each step of the process is independent and has got specific parameters and can be defined as follow :
Perception. is an abstraction of sensors. The input data are the raw information from the sensors. A parser is used to convert them in workable data set for further decision-making process
In **Perception Filter.** block a filtering policy is applied. The goal of this unit is to sort out the perceived elements between obstacles and other convoy vehicles. Among these vehicles a local leader is chosen using specific strategy.
The **Multi-Configuration.** unit applies the geometrical transformations required to change local leader position and orientation into virtual leader ones.

The **Decision-Making.** block corresponds to the application of the interaction model and the computing of the command law to be applied to the vehicle.
The last step in this process is an **Command Filtering.** which can corresponds to driving assistance filtering such as obstacle avoidance or to the introduction of a kinematic model for the smooth command for instance.

4.2 Detailed Description

This section aims at describing layers one by one following the introduction description and figure 3.

4.2.1 Perception

The perception takes as an input the raw data of the sensor associated to object detection algorithm. To be able to have reliable detection, sensors have to cover the surrounded environment of the vehicle as shown in fig. 4. The output of the perception unit is a list of localized object in the vehicle reference frame. Various kind of sensors can be used to performed this process such as stereo cameras, sonars belt, laser range finders,...

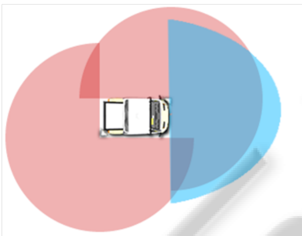

Figure 4: Sensors ideal coverage area.

4.2.2 Perception Filter

The goal of this unit is to analyse the output of the perception in order to remove noise in the data and to sort out detected objects. A Kalman filter has been chosen to filter the noise. A Kalman filter is a prediction/correction based filter which uses a transition model for the prediction and an observation model for the correction. As for the sorting of the objects a simple strategy has been used. the aim is to provide a classification of the environment in 3 class.

1. Object member of convoy
2. Object moving in same direction but not member of convoy
3. Object moving perilously.

This classification is based on dynamic study of perceived object.

Then, the final step of this filtering unit is a geometrical transformation aimed at expressing the coordinates of the detected objects into the vehicle reference frame. (Initially, their coordinates are expressed into the sensors reference frames)**...**

4.2.3 Multi-Configuration

As exposed before, each vehicle in the platoon can be seen as an agent that acts based only on its perceptions. For each agent, we define a leader among its neighbours in the platoon (see section 4.2.2). The agent computes its references based on the position of its leader by trying to maintain the desired lateral and longitudinal spacing and the correct orientation. Column formation platoon control functions are now well known and expose reliable properties. Consequently, it as been decided to base our approach on this elementary function. So, the key step is to translate leader local position in vehicle agent reference frame in order to be able to use column platoon function and integrates desired lateral and longitudinal distances.
As exposed in section 2, there are several types of configuration that can be grouped into several families (echelon, line, column). The multi configuration proposal is based on modification of perception by introduction of virtual leader vehicle. Indeed, as detailed in table 5, every formations are possible with the introduction of a virtual leader.

	Leader Perception	Virtual leader definition	Installation of control model	Lateral translation (T_x)	Longitudinal translation (T_y)
Echelon		T_x		Lateral distance	0
Line		T_x T_y		Lateral distance	Longitudinal distance
Column				0	0

Figure 5: Formations tab.

In order to determine position of virtual leader, several parameters are used: geometrics aspects, perception and configuration order. Indeed, a translation of la and lo is made in the referential of local leader. Position of virtual leader is defined by a 2D Transformation (figure 6) could be describe by following equation :

$$\begin{cases} x_v = x_r + l_a\, cos(\theta) + l_o\, sin(\theta) \\ y_v = y_r - l_a\, sin(\theta) + l_o\, cos(\theta) \end{cases} \tag{1}$$

where

- (x_v, y_v) virtual leader position
- (x_r, y_r) real leader position
- (l_a, l_o) lateral and longitudinal distances
- θ angle between cars.

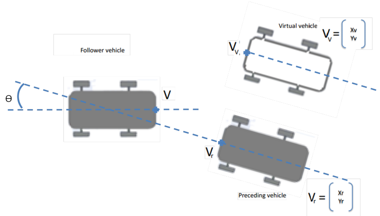

Figure 6: Virtual leader in multi configuration.

4.2.4 Interaction Model

A model of interaction inspired by physics has been chosen. This model, detailed in (El-Zaher et al., 2011b) has got two springs and a damper placed between the local leader and the follower vehicle (cf Figure 7). This model is virtual and unidirectional. Indeed to better control the interaction, the local leader vehicle is not affected by generated forces.

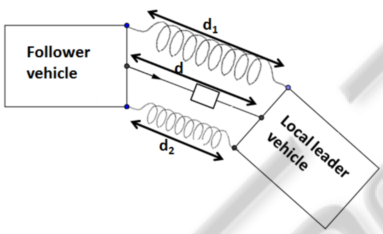

Figure 7: Interaction model.

The parameter of this model take into account the vehicles characteristics . This optimisation allow to keep a low latency and keep a real-time reactivity. A compositional verification of this system has been made in (El-Zaher et al., 2011a) to prove non collision event.

4.2.5 Command Filter

The command proposed by the interaction model must be adapted to the environment in order to deal with the presence of obstacles for instance. Several filters can be considered. The most simple is an emergency stop filter: in case of obstacles in a neighbourhood too close, the command is set to 0. Another filter presented in previous work (Franck Gechter and Koukam, 2010) and aimed at computing obstacle avoidance strategies can be apply. This obstacle avoidance device is based on a multi-agent system where the observation of an agents population lead to a modification of the vehicle command.

These filters require data from the perception. This is why a link is possible to bring directly sensors data from perception unit (or perception filter) to command filter as shown in the picture 8.

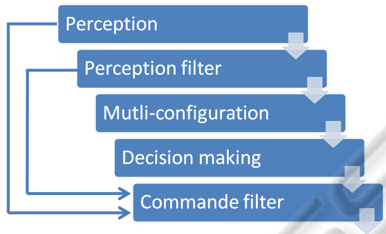

Figure 8: Command filter input.

4.3 Flexible and Adaptive System

As seen above, our proposal is based on layers. Each module takes, as an input, the output of preceding block. Thus, provided that the input and the output are correct, layers can be changed using other algorithms or strategies. Moreover, it is possible to combined some inputs or to combine in cascade several blocks of the same type. Finally, these changes in blocks can be performed in runtime

Here are two examples to illustrate this modularity:

1. Input combined and association in cascade

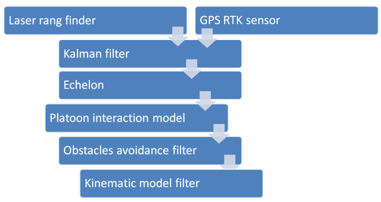

Figure 9: Input combined.

2. Interchanged blocks:

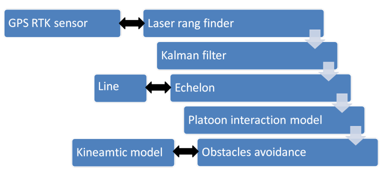

Figure 10: Association in cascade.

5 EXPERIMENTAL RESULTS

5.1 Global Overview

5.1.1 Vehicles Description

Vehicles used in the simulation represent (graphically and physically) the experimental laboratory's vehicles. They satisfy the physical constraints and share the same characteristics. In simulation, they are equipped with two 270 degrees virtual laser range finder, replica of LMS SICK 200 and with GPS-RTK simulation required to follow and study trajectories. Vehicles have the following characteristics: $1.8m$ width, $3.05m$ length, max steering angle=30 degrees and max speed=$12m/s$

5.1.2 Simulator

To assess the quality of our approach, simulations have been done using VIVUS simulator (Lamotte et al., 2010), VIVUS is a vehicle simulator based on PhysX for real physical behaviour developed by the SeT[3] laboratory.
This software can simulates behaviours for each vehicle such as perception with laser range finder or cameras, physical reaction between elements (wheels, car's parts,...),... Physical reaction are computed using the same physical law as real world (collision, gravity,...) and considering the peculiarity of the environment (friction with soil, materials of soils and walls,...). VIVUS has already been used to test various intelligent vehicle algorithms such as linear platoon control (Franck Gechter and Koukam, 2010) and (El-Zaher et al., 2011b), obstacle avoidance and driving assistance (Gechter et al.,) and (Dafflon et al., 2012), and intelligent crossroads simulations in (Dafflon et al., 2011).

5.1.3 Metrics and Analysis

Two informations are measured during experimentations:

- Lateral distance measures the spacing between the horizontal axes of two neighbour vehicles. In cases of column platoon, this distance should be null.
- Longitudinal distance represents the inter-vehicle distance between two neighbour vehicles.

Lateral and longitudinal distances are recorded by VIVUS simulator and analysed off-line by matlab scripts. thanks to these measures, we will explore:

[3] http://set.utbm.fr/

- General behaviour of the convoy route with GPS - Lateral and longitudinal distances a function of time - Lateral and longitudinal distances a function of speed.

5.1.4 Test Area

Simulations were performed on a 3D geo-localized model of the city of Belfort (France). Two different trajectories have been chosen. In the first trajectory, vehicles have to follow a circle around 25m of radius. The simulations are done many times (ie: 500 iterations) for the purpose a statistical studies about experimentations.

5.2 Experimental Results

Experimentations are made following two scenarios. The first simulates a convoy of vehicles in the column whereas the second simulates a echelon convoy.

5.2.1 5 Vehicle Platoon Convoy in Column

1. 5 vehicle platoon convoy in line :
In Figure 11, only the lateral gaps from the first, third, fourth and last follower are presented. We can see that the error between the measurement and instruction is amplified depending on the position of the vehicle in the convoy. The last follower error is between 0.07m and 0.55m, while the first follower error is between 0.12m and 0.01m. The difference between the measurement and setpoint comes from amplification errors due to the local approach. It is interesting to compare these measures to the width of a tire (about 0.2 m).

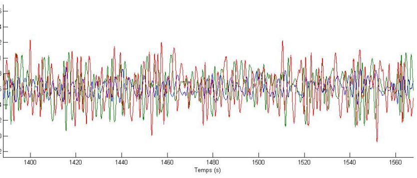

Figure 11: Lateral Gap in Platoon Convoy.

In Figure 12, only the longitudinal gaps from the first, third and last follower are represented. We can see that the error between the measurement and set point is amplified. The error of first follower is between 5.7m and 6.7m whereas the last follower is between 5.2 m and 6.4 m. The difference between the measurement and the reference is from an extension of the springs in the present interaction model.

2. 5 vehicle platoon convoy in echelon
Figure 13 shows the lateral deviation follower 1 and 5. We notice that the echelon formation does

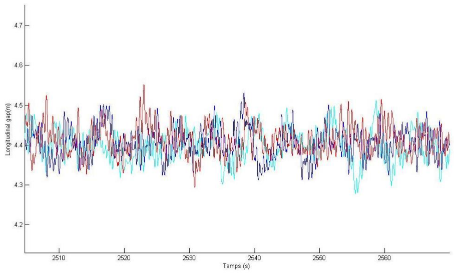

Figure 12: Longitudinal Gap in Column Platoon Convoy.

not lead additional oscillation as compared to a column formation. The virtual vehicle seems a reliable alternative for the inter-distance management of a multi-lateral configuration.

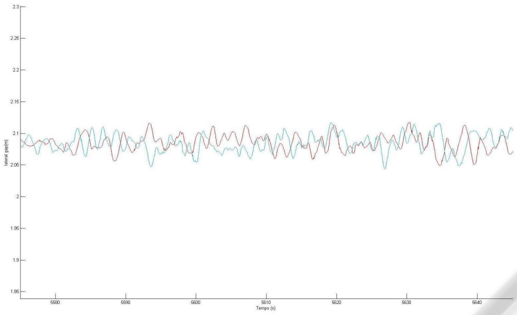

Figure 13: Lateral Gap in Echelon Platoon Convoy.

Figure 14 shows the longitudinal inter-distance measured on the train. We can notice that the error between the measurement and set point spreads by amplifying. The inter-distance of first follower is between 5.18m and 5.2m while the last follower is between 5.01m and 5.22 m.

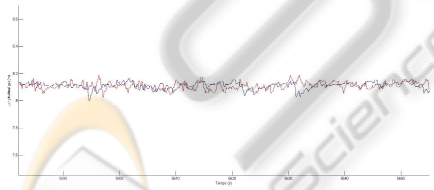

Figure 14: Longitudinal Gap in Echelon Platoon Convoy.

5.2.2 5 Vehicle Platoon Convoy in Circle

1. 5 vehicle platoon convoy in column
   As shown in Figure 15 the differences between first and last follower, we can see besides the residual oscillations that the differences between vehicles are of the same order as in previous experiment. From the first follower to the last, the longitudinal gap is in a range from 5.87m to 6.04m.

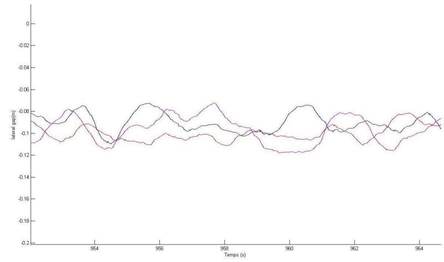

Figure 15: Lateral Gap in Column Platoon Convoy.

Figure 16 represents the lateral error from the first follower to the last. Thus, while the measurement of the first Follower are in the same order as before, the last follower describes an lateral error between -0.1 and 0.2m.

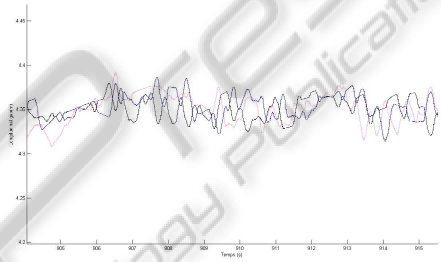

Figure 16: Longitudinal Gap in Column Platoon Convoy.

2. 5 vehicle platoon convoy in echelon
   Figure 17 describes the evolution in time of the lateral deviations. it may be noted that the position in the convoy does not increase the oscillations. Indeed, with a circular path, the error is comprised between 0.09 and 0.11m (less than the width of a tire). It is interesting to note that the train keeps the same stability with 3 to 5 vehicles.

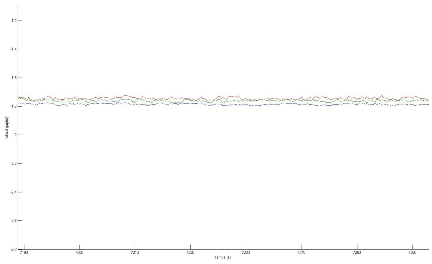

Figure 17: Lateral Gap in Echelon Platoon Convoy.

Figure 18 shows that the most the vehicle is near the center, the more the error on the longitudinal set point is large. The reasons of this result are the links between anticipation, speed elongation and virtual vehicle transformation.

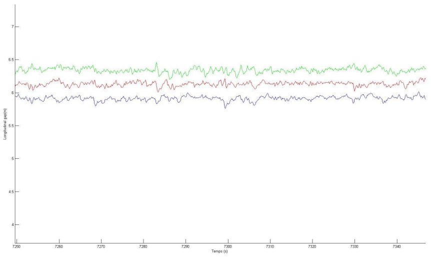

Figure 18: Longitudinal Gap in Echelon Platoon Convoy.

6 CONCLUSIONS

The paper presents a agent approach for platoon system through a generic and modular decision process for autonomous vehicle in platoon system. In this model, different layer is are proposed and combined to define behaviour. Each layer allow facilitate the processing done in next step. The main advantages proposed by this system is a run time and self adaptation to environment. This solution was successfully tested in simulation and results obtained are encouraging to test using real laboratory vehicles and real sensors. In order to continue this research, we are now working on generic and emerging perception filter to adapt perception to any sensors.

Those works are done with the support of the French ANR (National Research Agency) through the ANR-VTT *SafePlatoon* [4] project (ANR-10-VPTT-011).

REFERENCES

Caicedo, R., Valasek, J., and Junkins, J. (2003). Preliminary results of one-dimensional vehicle formation control using structural analogy. *Control Conference*.

Cartade, P., Lenain, R., Thuilot, B., and Berducat, M. (2002). Formation control algorithm for a fleet of mobile robots. *3rd International Conference on Machine Control and Guidance*.

Chan, E., Gilhead, P., Jelinek, P., and Krejci, P. (2011). Sartre cooperative control of fully automated platoon vehicles. *18th World Congress on Intelligent Transport Systems*.

Dafflon, B., Contet, J.-M., Gechter, F., and Gruer, P. (2012). Toward a reactive agent based parking assistance system. *The 24rd IEEE International Conference on Tools with Artificial Intelligence ICTAI, IEEE Computer Society*.

Daffon, B., Gechter, F., Contet, J., Abbas-Turki, A., and Gruer, P. (2011). Intelligent crossroads for vehicle platoons reconfiguration. *International Conference on Adaptive and Intelligent Systems*.

Daviet, P. and Parent, M. (1996). Longitudinal and lateral servoing of vehicles in a platoon. *IEEE Intel ligent Vehicles Symposium*, pages 41 – 46.

El-Zaher, M., Contet, J., Gruer, P., and Gechter, F. (2011a). Towards a compositional verification approach for multi-agent systems : Application to platoon system. *First International workshop on Verification and Validation of multi-agent models for complex systems (V2CS)*.

El-Zaher, M., Gechter, F., Gruer, P., and Hajjar, M. (2011b). A new linear platoon model based on reactive multi-agent systems. *The 23rd IEEE International Conference on Tools with Artificial Intelligence ICTAI, IEEE Computer Society*.

Franck Gechter, Jean-Michel Contet, P. G. and Koukam, A. (2010). A reactive agent based vehicle platoon algorithm with integrated obstacle avoidance ability. *Self-Adaptive and Self-Organizing Systems*.

Gechter, F., Contet, J., Gruer, P., and Koukam, A. Car driving assistance using organization measurement of reactive multi-agent system. *Procedia CS1(1): 317-325*.

Gehrig, S. and Stein, F. (2001). Elastic bands to enhance vehicle following. *IEEE Conference on Intelligent Transportation Systems*, pages 597 – 602.

Hedrick, J., Tomizuka, M., and Varaiya, P. (1994). Control issues in automated highway systems. *Control Systems, IEEE*, 14(6):21 –32.

Lamotte, O., Galland, S., Contet, J.-M., and Gechter, F. (2010). Submicroscopic and physics simulation of autonomous and intelligent vehicles in virtual reality. *Advances in System Simulation, International Conference on*, 0:28–33.

Levine, W. and Athans., M. (1966). On the optimal error regulation of a string of moving vehicles. *IEEE Transactions on Automatic Control*.

o Yeong Yi, S. and Chong., K.-T. (2005). Impedance control for a vehicle platoon system. *Mechatronics*.

Riess, R. (2000). Qualification d'un tlmtre balayage laser pour la robotique mobile : Intgration et exprimentations. *Master's thesis*.

[4]http://safeplatoon.utbm.fr