Acceleration Signal Based Linear Formation Driving Model: Algorithmic Description and Simulation Results

Javier J. Sánchez-Medina[1], Alberto Broggi[2], Manuel J. Galan-Moreno[1], and Enrique Rubio-Royo[1]

[1] CICEI – ULPGC, Spain
javier.sanchez.medina@ieee.org, mgalan@dmat.ulpgc.es, erubio@polaris.ulpgc.es
[2] Vislab, University of Parma, Italy
broggi@ce.unipr.it

Abstract. Platoon vehicles coordination is an important topic at Intelligent Transportation Systems these days. For coordinating two or more vehicles, it is needed both a communication method between them, and an environment sensing strategy enabling the triangulation and correction, when needed, of each vehicle relative position within the desired platoon.

In this research we present a new strategy to keep a group of vehicles in a fixed platoon, that may complement classic approaches. Usually, in a platoon, every follower vehicle try to keep a distance to the vehicle right ahead. That lateral and longitudinal control is kept considering the sensed distances by using laser, radar or vision.

In the present paper we want to propose a new concept that consists on sharing the leader's acceleration signal all across the whole vehicle platoon. In a few words, all the followers try to implement the leader's sensed and transmitted acceleration. Theoretically, two solids experiencing the same accelerations will reproduce identical trajectories while keeping the initial relative distances, if they start from the same initial non-zero constant speed.

In this paper we present this new concept, we list what are some of the technological challenges to be addressed before its implementation, and we finally share some initial simulation results.

1 Introduction

There are many researchers working on Cooperative and Formation Driving or Platoon Driving as evidence the yearly the Grand Cooperative Driving Challenge ([3]) or the VIAC Challenge ([1]). There is also many groups actively working on coordination for other purposes, like overtaking([2] and [4]).

For most of them there are three technologies used to detect the other vehicles and the environment: video, laser and radar detectors. When talking about vehicle coordination, we are assuming that the perception information is then shared between the vehicles (V2V) and/or with the infrastructure (V2I).

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Additionally, some approaches include Inertial Navigation Systems, but mainly for improving the precision of self odometry.

In this work we want to propose a new complementary way to tackle vehicle coordination where all the vehicles reproduce the exact acceleration signal as the leader, but with the precise timing.

Ideally, if all the member of the platoon suffered the same accelerations, their trajectories would be identical, no matter their mechanical or physical differences, while keeping their relative initial distances.

The benefits from such coordination model could include the following:

- **Drift not accumulative:** Since the coordination is reduced to a star like layout, with all the followers coordinating just with the leader, the drifts would not accumulate as we go backwards in the platoon. When the coordination method is local between pairs or small groups of cars, for instance, maintaining the distance to the vehicle ahead, it usually happens that drifts become worse and worse as going to the tail of the platoon.
- **Tighter reproduction of the leader's trajectory:** In the proposed methodology, not just the relative positions are adjusted, but the dynamics of every follower. Not just their positions but their speeds.
- **Robust Communications:** Short range radio transmissions are robust, quick and trustworthy. Contrary to what happens when using a communication medium that works on visual or near to visual spectrum, high frequency radio transmission are almost not affected by the environmental conditions, like dust, smoke, or poor weather, especially when the relative distance of all the vehicles in the platoon is quite reduced.
- **No need of V2I[1] communications:** This is a very big advantage in order to accelerate a possible implantation of such system, because only the cars need to be equipped, skipping expensive extensive investments for communications with the infrastructure.

This set of advantages cannot be enjoyed without a puzzle of technologies working like clockwork. All through this paper we propose some ideas to implement such concept alongside with some preliminary a set of simulated experiments in order to evaluate its feasibility.

2 Model Description

For better introducing the new proposed methodology we will consider only linear movement for the formation movement. The extension to planar or 3D movement is straightforward. Let us assume that the leader movement can be described as the result of a series of acceleration scalar values as shown in eq. 1.

$$a_L = \{a_{t_1}, a_{t_2}, a_{t_3}, \ldots\} \tag{1}$$

[1] Vehicle to Infrastructure.

Now let us presume that all the communication and technological delays are zero. Therefore, every new acceleration value at the leader is transmitted instantly to all of the followers alongside of the exact position and time where they were sensed. What we want each follower to do is to perform the needed changes on its driving control to produce an identical acceleration series exactly at the same positions the leader experienced them.

$$t_i = \frac{-vi + \sqrt{v_i^2 + 2a(x_{i+1} - x_i)}}{a_i} \tag{2}$$

Ideally, if every follower implements instantly at the precise desired location the needed acceleration, they will all form in a perfect platoon, with zero drift.

From the basic kinematics uniformly accelerated movement equations in non-relativistic physics we can easily derive that a solid at a specific position (x_i), with a specific velocity (v_i), and a specific acceleration (a_i), will have to wait for t_i (eq. 2) seconds to be sure it is at the desired position $x_{a_{i+1}}$ before implementing the just received next acceleration a_{i+1}.

If we assume that at the initial situation all the vehicles start from a constant non zero speed (v_i, $a_i = 0$) and the relative distance between the Leader and the i-th follower is $D_{i,L}$, the time that every follower needs to wait before implementing the first non zero acceleration transmitted by the leader is just $T_i = D_{i,L}/v_i$. Every vehicle starts implementing the first received acceleration t_i seconds after the leader.

For the rest of the received acceleration, every follower will only need to apply them right at the same pace as the Leader sampled it, which is the sampling period t_s.

However, to implement this system into a real world scenario there are a set of technological challenges to be addressed that could be categorized into Delay Challenges and Acceleration Shifting Challenges.

Delay Challenges

1. The actual values of acceleration need to be sampled with the highest possible precision and consistency. Luckily modern days IMUs[2] can be quite good at that.
2. The sampled Acceleration can include some additive electronic noise coming from the electronic and mechanical components on the Leader vehicle. So that Acceleration needs to be filtered somehow.
3. Assuming that the sampling period will not be zero, it needs to be as small as possible, but bigger enough so the first follower can effectively implement every new acceleration before the next one arrives.
4. All of the platoon vehicle system clocks should be in near to perfect synchronization.

[2] Inertial Measurement Units.

Acceleration Shifting Challenges

1. The servo controllers at the followers must be quick enough to performed the required control action in the minimum possible time for changing from the current to the desired acceleration.
2. It is needed a sort of expert system, like an Artificial Neural Network, robustly trained to jump to the desired acceleration by a correction on the driving controls of the vehicle, departing from the current speed and acceleration.
3. Once the control adjustment is done, there will be a transient period that should be as short as possible to keep the followers' acceleration shifting time under control.

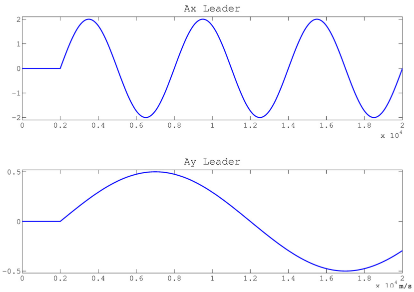

Fig. 1. Leader Acceleration

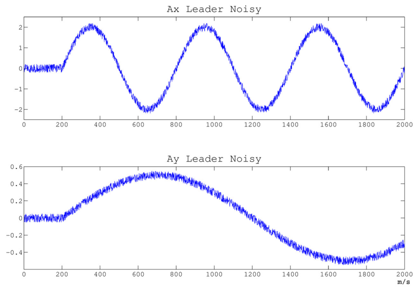

Fig. 2. Noisy Leader Acceleration

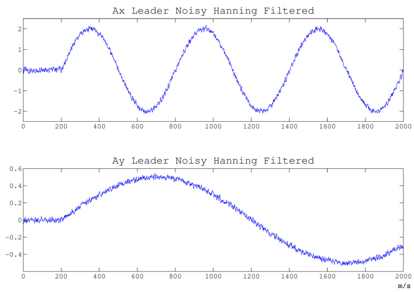

Fig. 3. Noisy Leader Acceleration Filtered

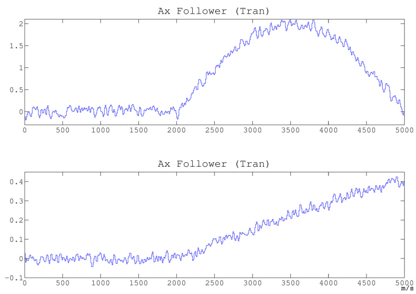

Fig. 4. Follower Acceleration, Including a Transient Phase

3 Experiments Developed

Now, in this section we will describe the simulations we designed as a very first step in order to evaluate the feasibility of its future implantation.

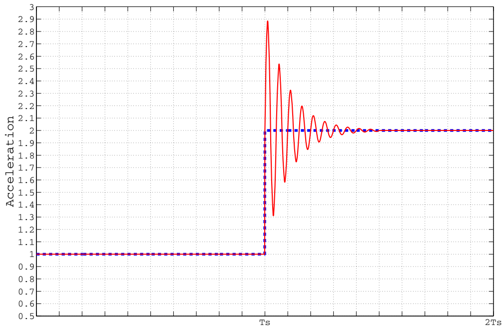

Fig. 5. Transient Acceleration Change Phase Simulated

$$A_{tran} = (a - a_0) * e^{-(5/T_{Tran})*t} * (-sin(2 * \pi * (10/T_{Tran}))) \qquad (3)$$

Fig. 6. Acceleration Transient Phase Equation

We have selected the following settings for the simulations performed:

– Different sampling periods.
– Different levels of white noise added to the sampled acceleration to simulate the electronic noise coupled from the electronic and mechanical devices to the IMU.
– A Hanning filter to simulate a quick filtering of the acceleration signal coming from the IMU (see eq. 4).
– We assumed that the transmission delay can be obviated, as long as the sampling period stays bigger than milliseconds.
– Regarding the transient period, we assumed an exponentially decrescent oscillatory transient, proportional in amplitude to the height of the "Step", or difference between the current and the desired acceleration (see Fig. 5 and eq. 3).
– Finally, we assumed a practically perfect synchronization of all the clocks. That is feasible since the GPS technology can provide around 10ns of time accuracy.

$$y[i] = 1/4(x[i] + 2x[i-1] + x[i-2]) \qquad (4)$$

With that setup, we have run a set of experiments varying two variables: The sampling period and the noise to signal relative amplitude on the leader. Every combination of values was studying following the next work flow:

1. Some white random noise is added to the acceleration signal (Fig. 2).
2. A Hanning filter is applied to the noisy acceleration signal (Fig. 3).

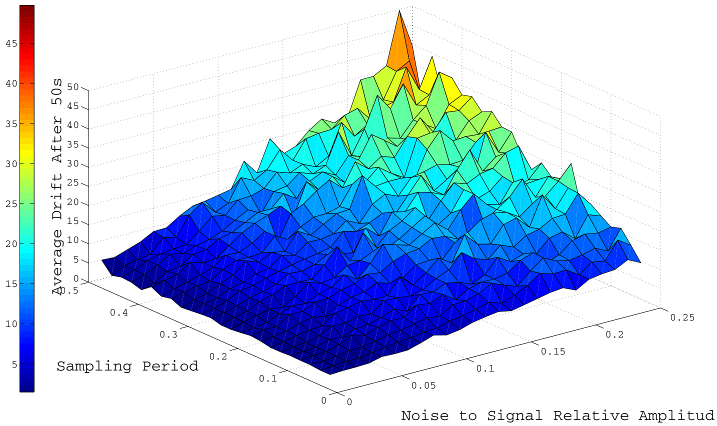

Fig. 7. Average Drift Surface

Table 1. Sampling Period (T_s) and Noise to Signal Relative Amplitude (NSR)

	Variable	Initial Value	Step	Final Value
Experiment Set #1	T_s	0.04	0.02	0.5
Experiment Set #1	NSR	0.01	0.01	0.25
Experiment Set #2	T_s	0.04	0.02	0.5
Experiment Set #2	NSR	0.005	0.005	0.10

3. We sampled that signal using a T_s sampling period, that signal is transmitted and the corresponding change is applied at the follower, producing a Transient Period for each new acceleration shifting (a fragment of the follower acceleration is represented in Fig. 4).
4. The Leader and Follower Trajectories are then simulated by simple integration, and the drift or distance difference with respect to the initial distance is computed.
5. We repeat this procedure for 30 times to average the Drift corresponding to each Sampling Period and Noise to Signal pair of values, each one lasting for 50 seconds.

Two sets of simulations were carried out, using the acceleration signal shown in Fig. 1 for the leader, and the following values for the Sampling Period and the Noise to Signal Ratio:

In Figure 7 we have the resulting Average Surface for the Experiment #1 (table 1). In Figure 8 is represented the standard deviation obtained for that experiments.

In Figure 7 one can observe that the average drift value seems to grow quicker by increasing the Noise to Signal Ratio (NSR) than by letting grow the sampling period.

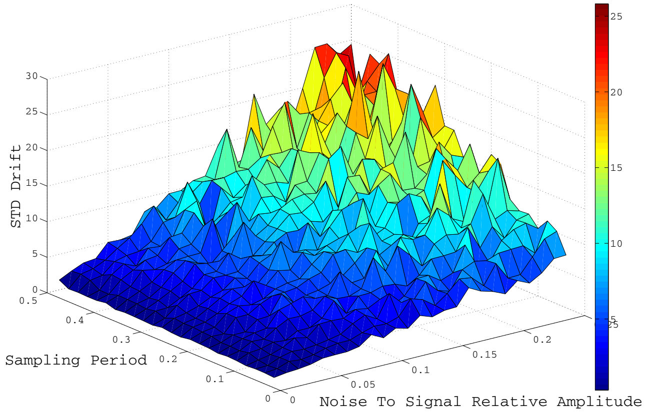

Fig. 8. Drift STD Surface

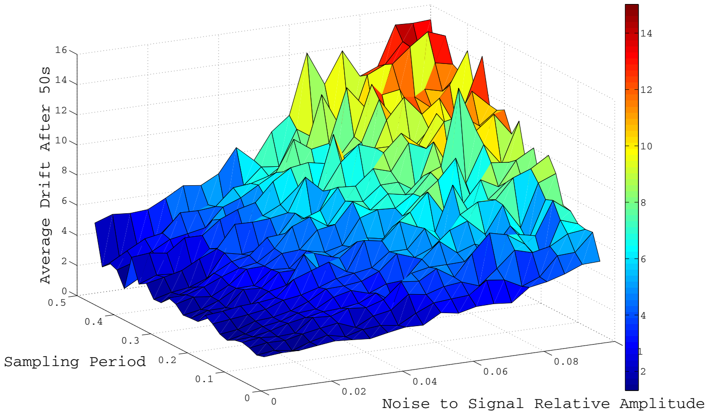

Fig. 9. Leader Acceleration

Additionally, the standard deviation (Figure 8) tell us that the probability distribution grows wider also at a higher pace when we increase the NSR.

To get a better view of that safe zone, we developed another set of experiments (Experiment Set #2 on table 1).

In Figure 9 we have the resulting Average Drift Surface for the Experiment #2.

In that figure one can see that beyond a 0.02 NSR (The noise amplitude 2% of the signal amplitude) the mean drift worsens dramatically. However, under that value of NSR, the Sampling period can move up to 0.3 seconds with similar results.

4 Conclusions and Future Work

In this paper we have presented the very initial results of a set of simulations for a new vehicle coordination methodology based on the transmission and "implementation" of the Leader's acceleration by all the followers.

Assuming some initial simplifications, like a zero transmission delay, we have concentrated our efforts on analyzing how robust is this system regarding two fundamental variables: The acceleration sampling period and the relative amount of noise that may poison the acceleration calculation at the leader's Inertial Measurement Unit.

We have observed how the system seems decently consistent regarding the sampling period. But we cannot tell the same regarding the Noise to Signal Ratio. The noise level seems to be hardly affecting this proposed coordination methodology, and we believe it may be an Achilles heel if not carefully addressed. Depending on the actual nature of that noise, if it were gaussian it could be possibly filtered just by using a more aggresive low-pass filter.

We realize that there is still a very important piece of the puzzle that needs to be studied before moving on: Can we train a sort of expert system, like an Artificial Neural Network, in a way that provide us with the vehicle control change required for a follower to, starting at a specific acceleration and speed state, be able to adapt its acceleration value getting reasonably close to the received leader's acceleration?

In this research, we have simulated that the shifting between the current and the desired acceleration takes only the half of the sampling period, through an exponentially decrescent oscillatory transient. Even considering that the acceleration changes will be small, proportionally to the sampling period, we need to study, using real-world data, that it can be done in a such short period of time.

All in all, considering that the proposed approach is a brand new one, we are willing to go and investigate if it could be implemented, sorting out that technical problems, to be implemented as a complement to the existing methods.

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