Virtual Vehicle Approach for Longitudinal Control in Urban Environments

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Abstract. Dealing with the control of autonomous vehicles on urban environments is a highly complex task due to the number of possible scenarios to consider. On this work, we present a virtual vehicle approach for the management of several urban manoeuvres by considering them as an Adaptive Cruise Control (ACC) problem, from the longitudinal point of view. This solution is based on a centralised communication system which manages and analyses all the information incoming from the vehicles and the infrastructure on a limited area. In order to validate the performance of the proposal, an experiment has been carried out at the test track of the AUTOPIA program. On the experiment, several vehicles over an intersection were controlled by the central system.

1 Introduction

Thanks to the advances of today's technology, more and more vehicles on the market incorporate different driver aid systems to improve both safety and efficiency on roads. Most of these systems trigger signals to inform the driver about unexpected circumstances or to suggest actions upon the vehicle – e.g. warnings about pedestrian presence or messages suggesting to use a lower/higher gear. However, with the continuous growth of the number of vehicles on roads, the development of systems able to replace the driver under determined scenarios is being demanded. For example, by implementing automatic steering control systems with a higher degree of accuracy than human drivers have, the road capacity can be increased since the needed width for road lanes is lower [1]. Likewise, longitudinal systems would help keeping a shorter distance with the vehicle in front, improving also the fuel consumption on vehicles.

One of the first systems developed and marketed for autonomous longitudinal control in vehicles is the Cruise Control (CC). Thanks to this system, drivers are able to set a reference speed and transfer the control of the throttle to the on-board computers on the vehicle. Nowadays, there are other solutions – some of them still in the experimental phase – that go one step further and by using

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proximity sensors in the front of the vehicle – e.g. cameras, lidars, radars or even inter vehicle communications – are able to detect the presence of other vehicles in front. This permits to adapt the reference speed of the vehicle according to the speed of the vehicle in front while also keeping a safe distance. These systems are known as Adaptive CC (ACC) or Cooperative Adaptive CC (CACC), being this last related to the usage vehicle-to-vehicle communications systems.

A particular case of the CACC is the platooning or road train scenario [2,3]. A platoon is a formation of vehicles where a leading vehicle sets both the trajectory and speed to be followed by the trailing cars. One of the first demonstrations related to the platooning problem is described in [3]. In this experiment, a group of 8 cars were driven in a platooning formation over a special road with magnetic marks on it. The information was shared by the cars using an inter-vehicle communications system.

Solutions as the ACC systems are normally considered only for freeway scenarios or those where vehicles speed is higher than 35 km/h. However, their performance in urban environments has also been studied in previous works, taking special attention to the traffic jam scenarios where the system must be able to deal with the high dynamic of the vehicle [4,5].

In this work, a virtual vehicle approach for longitudinal control in urban environments is presented. The main goal is to develop a system able to control several vehicles inside an urban area by considering all the possible scenarios – i.e. merging, roundabouts, crossroads, etc. – as an ACC problem. An introduction to the virtual vehicle concept was already presented by the authors in [6], where an automatic on-ramp merging system for traffic jams scenarios is described. On that work, a centralised system was able to control the speed of the vehicle entering to the main road and the movement of one of the cars – previously selected by an decision algorithm – to smoothly yield a space on the main road for the entering vehicle.

This work will be an extension of this system, including crossroads and roundabouts scenarios. This will reduce the longitudinal control problem to two main tasks: (i) projection of the vehicles positions over a 1-dimension space, where the global controller will finally determine the speed and distance reference for each vehicle in the area and (ii) management of the entrances and exits to the different platoon groups in the area.

2 Control Scheme

An urban environment, as the one showed on Figure 1, may have several subscenarios – as intersections, roundabouts or merging – that one could think must be addressed independently. However, from the longitudinal point of view, they are all very similar, in essence. For example, when a human driver approaches a roundabout, he performs the same actions that for a merging manoeuvre: reduces his vehicle speed prior to the roundabout entrance – merging point – and enters only when there is available space for the car. The same situation occurs on non-signalised intersections, being the center of the intersection the

Fig. 1. AUTOPIA's test track at the Center for Automation and Robotics

merging point. So, with these similarities as start, the question remaining is how to generalise these scenarios?

Before answering that question, we must introduce the control scheme implemented for the urban environment. The AUTOPIA Program[1] — research group where this work has been carried out — has a long record on the development of autonomous vehicles, using mass produced vehicles and testing on real roads [7]. Previous works [8], [9] have presented the control architecture designed for a single car, based on a classical perception-planning-actuation scheme. However, in this case the vehicle is just the smaller component of a bigger entity: the urban environment. For addressing the control of all the vehicles inside an area, we have proposed on a previous work the implementation of a central management system (CMS) based on communications among the vehicles and the infrastructure [6], [10]. This leads to a control scheme with four stages:

1. *Perception*: In this stage, the vehicles and the infrastructure collect the information from all the on-board sensors and send it to the CMS. Each vehicle includes information about its state — position, orientation, turning intention and so on – while the infrastructure may include information about lane occupancy or state of traffic lights in the area. It is necessary to remark that the CMS only controls the information of a limited area, however it could also include some information sent by neighbours CMS [10].
2. *Management*: The CMS analyses all the information it receives from the perception stage in order to find the best way to resolve the different traffic situations. To this end, it takes into account the state of the traffic and the vehicles driving in the area. Once analysed, the system sends back the relevant information to the vehicles and infrastructure.
3. *Planning*: With the information received from the CMS, the vehicles and the infrastructure evaluate the situation and choose the best alternative to improve the traffic flow.
4. *Actuation*: Finally, the decisions made in the last stage are sent to the vehicles and infrastructure actuators. For example, for a traffic light this may indicate to change the state – light color – while for a vehicle it may change its speed by actuating either over the brake or the throttle.

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[1] `http://www.car.upm-csic.es/autopia`

3 Virtual Vehicle Approach

As was mentioned on the previous sections, the concept of the virtual vehicle was previously introduced on [6], where it was addressed the problem of merging the vehicles of a secondary road on a main one. For this, the CMS controls the speed of the vehicles on the secondary road prior to the merging point. At the same time, it selects a car, within those on the main road, which yields a space to the one entering. To that end, the system approaches the manoeuvre to an ACC problem, using a virtual projection of the merging vehicle over the main road.

Figure 2 shows an image of the merging scenario. Top figure represents the beginning of the merging manoeuvre, while the bottom figure shows the final state of the manoeuvre. The vehicle highlighted in green is the merging car; the blue car is the vehicle which yields to the merging one and the orange vehicle is the reference for the ACC. Both blue and orange car are selected by the CMS according to the traffic flow on the main road and the speed of the merging vehicle.

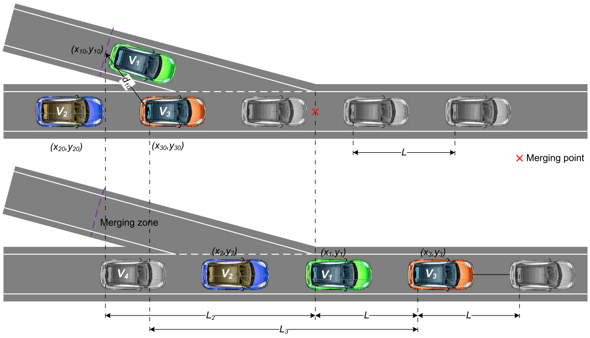

Fig. 2. Scheme for the merging scenario. Top image: beginning of the manoeuvre. Bottom image: end of the manoeuvre.

A simplified scheme of the manoeuvre is shown on Figure 3. One can appreciate on the image that the virtual position of the merging vehicle corresponds to the projection of the real position on the main lane. Once the virtual point is determined, the vehicles are controlled as for an ACC, using as reference the leader vehicle previously selected – orange car on Figure 2. In order to provide the space for the merging vehicle, the distance between the reference car and the blue car increases from L to $2L$ as they approach to the merging point. On its turn, the speed of the merging vehicle is adapted so the distance from the virtual point to the leader vehicle is L at the merging point. In this way, when the vehicle merges on the main road, it is already part of the traffic flow, with a low relative speed among the vehicles. This contributes to reduce the wave effect on the main lane [6].

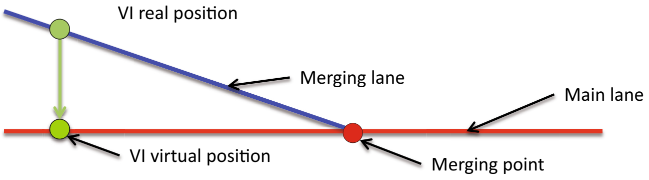

Fig. 3. Simplified scheme for the merging scenario

In order to apply this approach to intersections and roundabouts, we must first determine how to estimate the virtual position of the merging vehicle on those scenarios. For the roundabout, the easier method is to consider the inner trajectory as the main road, being each one of the entrances/exits secondary roads. In this way, we respect the regulations about priorities for roundabouts. Moreover, with this method each entrance has a different merging point as is shown on Figure 4.

On its turn, for the intersection manoeuvre there is not a main lane to highlight as for the roundabout. For this reason, we propose to considerer a virtual lane where the position of the vehicles on the 4 branches of the intersection are projected. The proposed lane is related to the signed distance to the intersection — positive when approaching and negative when moving away — leading to an easy calculation of the virtual position of the vehicles. An example of the virtual lane applied to an intersection is showed on Figure 5. On the left image one can appreciate the position of the vehicles over each branch, while the projection of the vehicles over the virtual lane is shown on the right image.

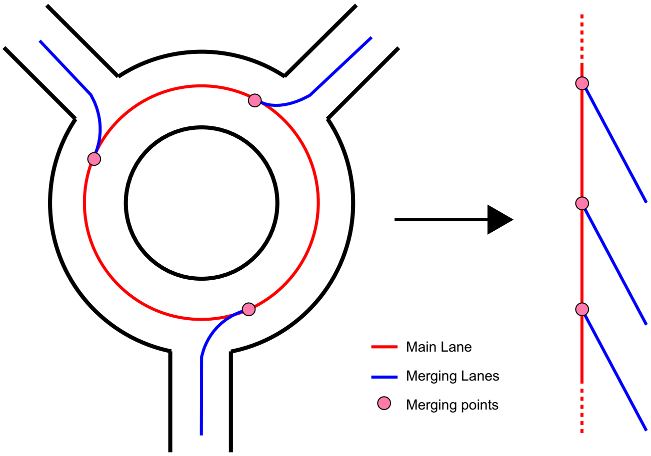

Fig. 4. Roundabout scheme

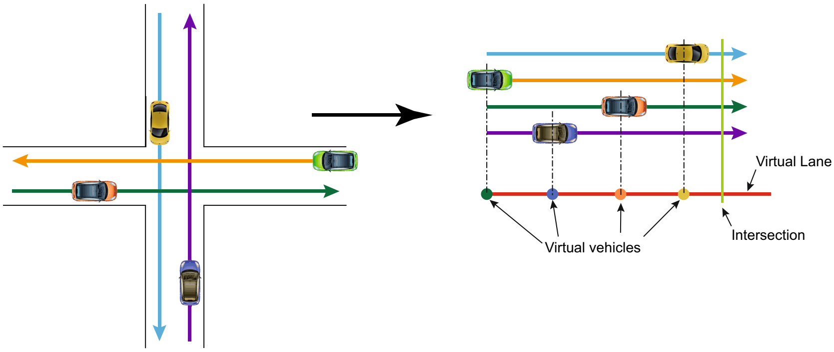

Fig. 5. Intersection scheme

4 Application Example

In order to show the applicability of the virtual vehicle approach, we present the results obtained during a real experiment performed at the Center for Automation and Robotics. The experiment was carried out using 4 vehicles of the AUTOPIA program at the intersection of the test track shown on Figure 1. For the experiment, one of the vehicle was manually driven while the other three performed and ACC according to the instructions sent by the CMS.

Figure 6 shows the position evolution for each vehicle over the time. At the same time, Figure 7 shows the absolute value of the distance to the intersection, that is, the projection over the virtual lane. One can appreciate that the system was able to manage the intersection without any risky situation. As the manually driven vehicle approaches the intersection – blue line – the other vehicles do it

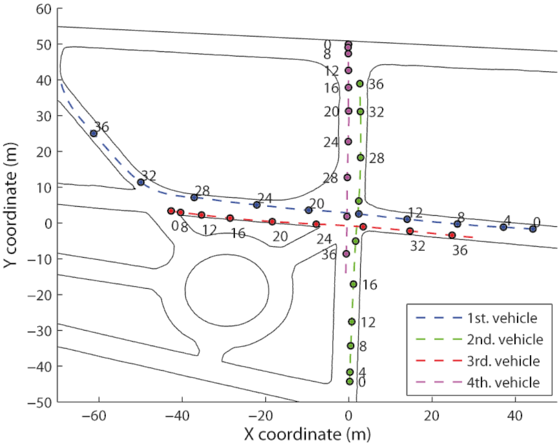

Fig. 6. Position of the vehicles during the experiment

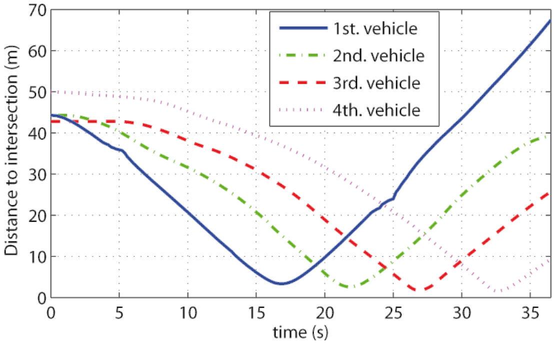

Fig. 7. Evolution of the distance to the intersection for each vehicle

as well, but keeping a distance gap that guarantees any risky situation around the intersection is avoided. For this experiment, the distance gap between GPS antennas was set to 12 metres.

5 Concluding Remarks

We have presented on this work a virtual vehicle approach for the management of different manoeuvres on an urban scenario. The proposal is based on a control architecture with a centralised communications for a limited area. All the information of the area is analysed by a central management system, which is in charge of determining the best way to handle the control of the vehicles. Thanks to this approach, the different scenarios as roundabout, merging and intersections are managed, from the longitudinal point of view, as an ACC problem.

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References

1. Shladover, S.: Cooperative (rather than autonomous) vehicle-highway automation systems. Intelligent Transportation Systems Magazine 1, 10–19 (2009)
2. Robinson, T., Chan, E., Coelingh, E.: Operating Platoons On Public Motorways: An Introduction To The SARTRE Platooning Programme. In: 17th World Congress on Intelligent Transport Systems (2010)
3. Shladover, S.E.: The California PATH Program of IVHS research and its approach to vehicle-highway automation. In: Proceedings of the Intelligent Vehicles 1992 Symposium (1992)

4. Naranjo, J.E., González, C., García, R., de Pedro, T.: Cooperative Throttle and Brake Fuzzy Control for ACC+Stop&Go Maneuvers. IEEE Transactions on Vehicular Technology 56(4), 1623–1630 (2007)
5. van Arem, B., van Driel, C.J.G., Visser, R.: The impact of cooperative adaptive cruise control on traffic-flow characteristics. IEEE Transactions on Intelligent Transport Systems 7(4), 429–436 (2006)
6. Milanés, V., Godoy, J., Villagrá, J., Pérez, J.: Automated On-Ramp Merging System for Congested Traffic Situations. IEEE Trans. on Intelligent Transportation Systems 12(2), 500–508 (2011)
7. Milanés, V., Onieva, E., Pérez, J., Villagrá, J., Godoy, J., Alonso, J., González, C., de Pedro, T., García, R.: AUTOPIA Program Advances: How to Automate the Traffic? In: Moreno-Díaz, R., Pichler, F., Quesada-Arencibia, A. (eds.) EUROCAST 2011, Part II. LNCS, vol. 6928, pp. 374–381. Springer, Heidelberg (2012)
8. Pérez, J., González, C., Milanés, V., Onieva, E., Godoy, J., de Pedro, T.: Modularity, Adaptability and Evolution in the AUTOPIA architecture for Control of Autonomous Vehicles. In: Proceedings of the IEEE ICM, April 14-17, pp. 1–5 (2009)
9. Milanés, V., Alonso, J., González, C., Bouraoui, L., Ploeg, J., de Pedro, T.: Cooperative maneuvering in close environments among cycabs and dual-mode cars. IEEE Trans. on Intelligent Transportation Systems 12(1), 15–24 (2011)
10. Milanés, V.: Sistema de Control de Tráfico para la Coexistencia entre Vehículos Autónomos y Manuales mediante Comunicaciones Inalámbricas. PhD Thesis. Universidad de Alcalá (2010)