Reliable and Safe Control Navigation of Multi-Vehicle Formation in Complex Urban Environment

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Keywords: Autonomous vehicles; Cooperative navigation; Hybrid (continuous-discrete) and Stochastic multi-controller architectures; Dynamic and safe obstacle avoidance; Estimation.

I. Context and overall objectives

In recent years, the development of fully autonomous vehicle for transportation tasks has received even more attention from different laboratories / companies throughout the world [Burns 13]. The focus of the proposed PhD thesis is passengers' transportation in midtown or in closed/dedicated areas like inside big companies, amusement parks, airports, etc. which need autonomous shuttles between their different areas. Although if these kind of environments are generally delimited and the AGV’s dynamic is not as important as cars in motorways, nevertheless the most important components of autonomous navigation must be developed and mastered to deal with the different complex situations (which could be encountered by the vehicle) or to the dynamic and uncertainty of the environment. Another important issue of the proposed PhD subject is related to multi-vehicle navigation and coordination. Several laboratories/companies around the world are more and more involved in the general field of autonomous multi-vehicle navigation in formation [Adouane 16, chapter 6]. It is notably the case at Institut Pascal since 2000 [Bom 06], [Avanzini 10], [Benzerrouk 11], [Vilca 15a]. The coordination of a group of vehicles to perform specific tasks show important benefits and large application in different areas such as: passengers and goods transportation, agriculture, surveillance, etc. Nevertheless, some difficult problems need to be solved to achieve a suitable and reliable coordination. The numerous interactions between vehicles themselves and their environment, as well as the complexity of autonomous navigation in complex environment do not permit the direct use of neither classical planning nor control techniques. In fact, the context of multi-vehicle systems navigating in a dynamic and uncertain environment is a very challenging subject.

The proposed PhD subject will be achieved in the context of collaborative research between Institut Pascal/IMobs3 (France) and Cranfield University (United Kingdom). More specifically, the candidate will evolve in the MACCS team of Institut Pascal (when the PhD candidate will be in France) and in Autonomous Systems team of Cranfield University (when he will be in United Kingdom).

II. Theoretical approach and main objectives

The inherent complexity of the cooperation/coordination of the movements between autonomous entities will be addressed, during this PhD thesis, while deeply investigating the potentialities of multi-controller architectures [Adouane 16] which have as main objective to break the complexity of the tasks to be carried out while ensuring the demonstration of stability/safety of the overall control architecture. Indeed, autonomous multi-vehicle systems can move in very complex environments and requires in addition an accurate and safe coordination between the vehicles (to cross an intersection for instance or to take a roundabout). Thus, to control this complexity, it is planned to break up the overall control dedicated to the achievement of the complex task into a group of accurate and reliable elementary behaviors/controllers (obstacles avoidance [Adouane 11], trajectory following [Benzerrouk 09], navigation in formation [Benzerrouk 10], [Vilca 13], etc.) which link different information given by the sensors to the actions of robots. An important part of the targeted work in

1 http://ip.univ-bpclermont.fr/
2 http://www.cranfield.ac.uk/
this PhD subject corresponds to find the optimal balance between the distribution of the control among the different vehicles and the control part which could be centralized using for instance a Leader vehicle or the infrastructure. This kind of partial-hierarchy for controlling the group of vehicles could be relevant for intersection crossing or roundabout navigation.

It is targeted in this PhD thesis to develop an enhanced multi-controller architecture [Adouane 16] in order to perform safe and flexible navigation strategy for a fleet of vehicles in complex environments (e.g., cluttered, uncertain and/or dynamic) and new situations [Oh 14]. The main targeted investigations in this thesis are related to:

- **Demonstration of the overall hybrid** (continuous / discrete) [Branicky 98] [Asarin 00] [Adouane 09] **control architecture stability and reliability even in the presence of uncertainties** (due for instance to the perceptions and/or to the robot modeling). The degree of robustness of the system to the noise/uncertainties should be quantified via **suitable metrics** in order to have a rigorous analysis of the control performances. This will be done while **enhancing the modeling** and the applied control laws / strategies to deal better with the uncertainty [Sequeira 11] and the vehicle dynamic; the objective is to lead, among others, to safer and more comfortable vehicles behaviors, etc.

- **On-line adaptation of control algorithms or control law parameters w.r.t. the current localization accuracy supplied by the vehicle sensors.** The aim is to optimize the performances of the multi-vehicle system (mainly the vehicles velocities) w.r.t. the confidence in localization / perception measurements [Sequeira 11], so that safety is never jeopardized. It is intended to rely on **stochastic and Lyapunov-based control techniques.**

- **Dynamic obstacle avoidance.** The objective is to ensure the Multi-Vehicle System (MVS) a greater autonomy while allowing them to avoid dynamic obstacles [Shanmugavel 10] [Adouane 11] during formation navigation. Here also, suitable metric will be used to quantify the MVS safety.

- **Dynamic reconfiguration of the fleet.** The challenge consists in guaranteeing the stability and the safety of the multi-vehicle system at the time of the transitions between configuration [Benzerrouk 14] [Vilca 14] (e.g., line towards square, triangle towards line, etc.). This will make possible to change online the space configuration of the multi-vehicle system according to the context of navigation (e.g., to pass from a triangle configuration towards a line if the width of the navigation way is not sufficient). The developed concepts could **permit also reliable merging and separation of platoons,** or only single vehicle w.r.t the MVS formation. This could be resolved notably while taking inspiration from the already developed Leader-Follower approach and the proposed techniques of formation reconfiguration [Vilca 15a].

- **Dynamic and safe intersection/roundabout traffic management.** The challenge consists in guaranteeing the stability and the safety of the MVS at the time of transitions between the individual controls of each vehicle to the phase of coordinating the MVS in the intersections [Benzerrouk 14]. The degrees of control stability and robustness to noise [Thrun 05] should be quantified here also via suitable metrics.

**III. Simulation and experimental platforms**

The proposed control architecture will be tested first with an accurate simulator used in Institut Pascal (cf. Figure 1(a)). In terms of experimental validation, it is planned to produce an overall experimentation involving 5 autonomous VIPALAB (navigating in formation for a part) in PAVIN (Plate-forme d’Auvergne pour Véhicules INtelligents) platform (cf. Figure 1(b) and (c)) while taking into account the modelling/perceptive/localization uncertainties and the presence of a conventional vehicle (with a driver) in the environment. The conventional vehicle and the pedestrians have as objective to force the autonomous vehicles to adapt their configuration and trajectories while maintaining a high level of navigation safety and flexibility. The final experiment aims also to show reliable intersection and roundabout management between the navigating VIPALABs. Other validations involving hardware in the loop validation of algorithms would be carried out at Cranfield.

![Figure 1 Simulation and experimental platforms](image-url)
Expected candidate background:
- Good mathematical background
- Programming (skills in C++ and/or Java, Matlab/Simulink)
- Basic knowledge on mobile robot control and/or multi-agent systems will be appreciated

**Deadline for applications:** June 20th, 2016

**Starting date:** Between September and October 2016.

**Candidacy and contacts:**
The candidates should send ASAP, a CV, a motivation letter, 1 recommendation letter (at least), a list of referees and the Master results for:
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**References:**


