Activity Report 2018

Project-Team RITS

Robotics & Intelligent Transportation Systems

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Project-Team RITS

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2. Overall Objectives

2.1. Overall Objectives

The focus of the project-team is to develop the technologies linked to Intelligent Transportation Systems (ITS) with the objective to achieve sustainable mobility by the improvement of the safety, the efficiency of road transport according to the recent "Intelligent Vehicle Initiative" launched by the DG Information Society of the European Commission (for "Smarter, Cleaner, and Safer Transport"). More specifically, we want to develop, demonstrate and test some innovative technologies under the framework of LaRA, "La Route Automatisée [1]" which covers all the advanced driver assistance systems (ADAS) and the traffic management systems going all the way to fully automated vehicles.

These developments are all based on the sciences and technologies of information and communications (STIC) and have the objective to bring significant improvements in the road transport sector through incremental or breakthrough innovations. The project-team covers fundamental R&D work on key technologies, applied research to develop techniques that solve specific problems, and demonstrator activities to evaluate and disseminate the results.

The scientific approach is focused on the analysis and optimization of road transport systems through a double approach:

1. the control of individual road vehicles to improve locally their efficiency and safety,

2. the design and control of large transportation systems.

The first theme on vehicle control is broadly based on signal processing and data fusion in order to have a better machine understanding of the situation a vehicle may encounter, and on robotics techniques to control the vehicle in order to help (or replace) the driver to avoid accidents while improving the performance of the vehicle (speed, comfort, mileage, emissions, noise...). The theme also includes software techniques needed to develop applications in a real-time distributed and complex environment with extremely high safety standards. In addition, data must be exchanged between the vehicles; communication protocols have thus to be adapted to and optimized for vehicular networks characteristics (e.g. mobility, road safety requirements, heterogeneity, density), and communication needs (e.g. network latency, quality of service, network security, network access control).

The second theme on modeling and control of large transportation systems is also largely dependent on STIC. The objective, there, is to improve significantly the performance of the transportation system in terms of throughput but also in terms of safety, emissions, energy while minimizing nuisances. The approach is to act on demand management (e.g. through information, access control or road charging) as well as on the vehicles coordination. Communications technologies are essential to implement these controls and are an essential part of the R&D, in particular in the development of technologies for highly dynamic networks.

In order to address those issues simultaneously, RITS is organized into three research axes, each of which being driven by a separate sub-team. The first axis addresses the traditional problem of vehicle guidance and autonomous navigation. The second axis focuses on the large scale deployment and the traffic analysis and modeling. The third axis deals with the problem of telecommunications from two points of view:

- *Technical*: design certified architectures enabling safe vehicle-to-vehicle and vehicle-to-vehicle communications obeying to standards and norm;

- *Fundamental*, design and develop appropriate architectures capable of handling thorny problems of routing and geonetworking in highly dynamic vehicular networks and high speed vehicles.

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[1]LaRA is a Joint Research Unit (JRU) associating three French research teams: Inria's project-team RITS, Mines ParisTech's CAOR and LIVIC.

Of course, these three research sub-teams interact to build intelligent cooperative mobility systems.

3. Research Program

3.1. Vehicle guidance and autonomous navigation

Participants: Mohammad Abualhoul, Zayed Alsayed, Pierre de Beaucorps, Younes Bouchaala, Pierre Bourre, Raoul de Charette, Carlos Flores, Maximilian Jaritz, Fernando Garrido, Farouk Ghallabi, Shirsendu Halder, Imane Mahtout, Kaouther Messaoud, Francisco Navas, Fawzi Nashashibi, Dinh-Van Nguyen, Renaud Poncelet, Danut-Ovidiu Pop, Luis Roldao, Anne Verroust-Blondet, Itheri Yahiaoui.

There are three basic ways to improve the safety of road vehicles and these ways are all of interest to the project-team. The first way is to assist the driver by giving him better information and warning. The second way is to take over the control of the vehicle in case of mistakes such as inattention or wrong command. The third way is to completely remove the driver from the control loop.

All three approaches rely on information processing. Only the last two involve the control of the vehicle with actions on the actuators, which are the engine power, the brakes and the steering. The research proposed by the project-team is focused on the following elements:

- perception of the environment,
- planning of the actions,
- real-time control.

3.1.1. Perception of the road environment

Participants: Zayed Alsayed, Raoul de Charette, Maximilian Jaritz, Farouk Ghallabi, Shirsendu Halder, Kaouther Messaoud, Fawzi Nashashibi, Dinh-Van Nguyen, Danut-Ovidiu Pop, Luis Roldao, Anne Verroust-Blondet, Itheri Yahiaoui.

Either for driver assistance or for fully automated guided vehicle purposes, the first step of any robotic system is to perceive the environment in order to assess the situation around itself. Proprioceptive sensors (accelerometer, gyrometer,...) provide information about the vehicle by itself such as its velocity or lateral acceleration. On the other hand, exteroceptive sensors, such as video camera, laser or GPS devices, provide information about the environment surrounding the vehicle or its localization. Obviously, fusion of data with various other sensors is also a focus of the research.

The following topics are already validated or under development in our team:

- relative ego-localization with respect to the infrastructure, i.e. lateral positioning on the road can be obtained by mean of vision (lane markings) and the fusion with other devices (e.g. GPS);
- global ego-localization by considering GPS measurement and proprioceptive information, even in case of GPS outage;
- road detection by using lane marking detection and navigable free space;
- detection and localization of the surrounding obstacles (vehicles, pedestrians, animals, objects on roads, etc.) and determination of their behavior can be obtained by the fusion of vision, laser or radar based data processing;
- simultaneous localization and mapping as well as mobile object tracking using laser-based and stereovision-based (SLAMMOT) algorithms.

Scene understanding is a large perception problem. In this research axis we have decided to use only computer vision as cameras have evolved very quickly and can now provide much more precise sensing of the scene, and even depth information. Two types of hardware setups were used, namely: monocular vision or stereo vision to retrieve depth information which allow extracting geometry information.

We have initiated several works:

- estimation of the ego motion using monocular scene flow. Although in the state of the art most of the algorithms use a stereo setup, researches were conducted to estimate the ego-motion using a novel approach with a strong assumption.

- bad weather conditions evaluations. Most often all computer vision algorithms work under a transparent atmosphere assumption which assumption is incorrect in the case of bad weather (rain, snow, hail, fog, etc.). In these situations the light ray are disrupted by the particles in suspension, producing light attenuation, reflection, refraction that alter the image processing.

- deep learning for object recognition. New works are being initiated in our team to develop deep learning recognition in the context of heterogeneous data.

- deep learning for vehicle motion prediction.

3.1.2. *Cooperative Multi-sensor data fusion*
Participant: Fawzi Nashashibi.

Since data are noisy, inaccurate and can also be unreliable or unsynchronized, the use of data fusion techniques is required in order to provide the most accurate situation assessment as possible to perform the perception task. RITS team worked a lot on this problem in the past, but is now focusing on collaborative perception approach. Indeed, the use of vehicle-to-vehicle or vehicle-to-infrastructure communications allows an improved on-board reasoning since the decision is made based on an extended perception.

As a direct consequence of the electronics broadly used for vehicular applications, communication technologies are now being adopted as well. In order to limit injuries and to share safety information, research in driving assistance system is now orientating toward the cooperative domain. Advanced Driver Assistance System (ADAS) and Cybercars applications are moving towards vehicle-infrastructure cooperation. In such scenario, information from vehicle based sensors, roadside based sensors and a priori knowledge is generally combined thanks to wireless communications to build a probabilistic spatio-temporal model of the environment. Depending on the accuracy of such model, very useful applications from driver warning to fully autonomous driving can be performed.

The Collaborative Perception Framework (CPF) is a combined hardware/software approach that permits to see remote information as its own information. Using this approach, a communicant entity can see another remote entity software objects as if it was local, and a sensor object, can see sensor data of others entities as its own sensor data. Last year we developed the basic hardware modules that ensure the well functioning of the embedded architecture including perception sensors, communication devices and processing tools.

Finally, since vehicle localization (ground vehicles) is an important task for intelligent vehicle systems, vehicle cooperation may bring benefits for this task. A new cooperative multi-vehicle localization method using split covariance intersection filter was developed during the year 2012, as well as a cooperative GPS data sharing method.

In the first method, each vehicle estimates its own position using a SLAM (Simultaneous Localization And Mapping) approach. In parallel, it estimates a decomposed group state, which is shared with neighboring vehicles; the estimate of the decomposed group state is updated with both the sensor data of the ego-vehicle and the estimates sent from other vehicles; the covariance intersection filter which yields consistent estimates even facing unknown degree of inter-estimate correlation has been used for data fusion.

In the second GPS data sharing method, a new collaborative localization method is proposed. On the assumption that the distance between two communicative vehicles can be calculated with a good precision, cooperative vehicle are considered as additional satellites into the user position calculation by using iterative methods. In order to limit divergence, some filtering process is proposed: Interacting Multiple Model (IMM) is used to guarantee a greater robustness in the user position estimation.

Accidents between vehicles and pedestrians (including cyclists) often result in fatality or at least serious injury for pedestrians, showing the need of technology to protect vulnerable road users. Vehicles are now equipped with many sensors in order to model their environment, to localize themselves, detect and classify obstacles, etc. They are also equipped with communication devices in order to share the information with other road users and the environment. The goal of this work is to develop a cooperative perception and communication system, which merges information coming from the communications device and obstacle detection module to improve the pedestrian detection, tracking, and hazard alarming.

Pedestrian detection is performed by using a perception architecture made of two sensors: a laser scanner and a CCD camera. The laser scanner provides a first hypothesis on the presence of a pedestrian-like obstacle while the camera performs the real classification of the obstacle in order to identify the pedestrian(s). This is a learning-based technique exploiting adaptive boosting (AdaBoost). Several classifiers were tested and learned in order to determine the best compromise between the nature and the number of classifiers and the accuracy of the classification.

3.1.3. *Planning and executing vehicle actions*

Participants: Pierre de Beaucorps, Carlos Flores, Fernando Garrido, Imane Mahtout, Fawzi Nashashibi, Francisco Navas, Renaud Poncelet, Anne Verroust-Blondet.

From the understanding of the environment, thanks to augmented perception, we have either to warn the driver to help him in the control of his vehicle, or to take control in case of a driverless vehicle. In simple situations, the planning might also be quite simple, but in the most complex situations we want to explore, the planning must involve complex algorithms dealing with the trajectories of the vehicle and its surroundings (which might involve other vehicles and/or fixed or moving obstacles). In the case of fully automated vehicles, the perception will involve some map building of the environment and obstacles, and the planning will involve partial planning with periodical recomputation to reach the long term goal. In this case, with vehicle to vehicle communications, what we want to explore is the possibility to establish a negotiation protocol in order to coordinate nearby vehicles (what humans usually do by using driving rules, common sense and/or non verbal communication). Until now, we have been focusing on the generation of geometric trajectories as a result of a maneuver selection process using grid-based rating technique or fuzzy technique. For high speed vehicles, Partial Motion Planning techniques we tested, revealed their limitations because of the computational cost. The use of quintic polynomials we designed, allowed us to elaborate trajectories with different dynamics adapted to the driver profile. These trajectories have been implemented and validated in the JointSystem demonstrator of the German Aerospace Center (DLR) used in the European project HAVEit, as well as in RITS's electrical vehicle prototype used in the French project ABV. HAVEit was also the opportunity for RITS to take in charge the implementation of the Co-Pilot system which processes perception data in order to elaborate the high level command for the actuators. These trajectories were also validated on RITS's cybercars. However, for the low speed cybercars that have pre-defined itineraries and basic maneuvers, it was necessary to develop a more adapted planning and control system. Therefore, we have developed a nonlinear adaptive control for automated overtaking maneuver using quadratic polynomials and Lyapunov function candidate and taking into account the vehicles kinematics. For the global mobility systems we are developing, the control of the vehicles includes also advanced platooning, automated parking, automated docking, etc. For each functionality a dedicated control algorithm was designed (see publication of previous years). Today, RITS is also investigating the opportunity of fuzzy-based control for specific maneuvers. First results have been recently obtained for reference trajectories following in roundabouts and normal straight roads.

3.2. V2X Communications for cooperative ITS

Participants: Gérard Le Lann, Mohammad Abualhoul, Younes Bouchaala, Fawzi Nashashibi.

Wireless communications are expected to play an essential role in ensuring road safety, road efficiency, and driving comfort o. Road safety applications often require relatively short response time and reliable information exchange between neighboring vehicles and road-side units in any road density condition. Because of the performance of the existing radio communications technology largely degrades with the increase of the

traffic density, the challenge of designing wireless communications solution suitable for safety applications is enabling reliable communications in highly dense scenarios.

To investigate this open problem and trade-off situations, RITS has been working on medium access control design for the IEEE 802.11p radio communication and the deployment of supportive solutions such as visible light communications and testing the use-cases for extreme traffic conditions and highly dense scenarios. The works have been carried out considering the vehicle behavior such as autonomous and connected vehicles merging, sharing, and convoy forming as platoon scenarios with considering the hard-safety requirements.

Unlike many of the road safety applications, the applications regarding road efficiency and comfort of road users, often require connectivity to the Internet. Based on our expertise in both Internet-based communications in the mobility context and in ITS, we are investigating the use of IPv6 (Internet Protocol version 6 which is going to replace the current version, IPv4, IoT) for vehicular communications, in a combined architecture supporting both V2V and V2I.

Communication contributions at RITS team have been working on channel modeling for both radio and visible light communications, and design of communications mechanisms, especially for security, service discovery, multicast, and Geo-Cast message delivery, and access point selection.

RITS-team has one of the latest certified standard communication hardware and tools supported by the partnership with the YoGoKo Company. All platforms (connected and autonomous vehicles) are equipped with state-of-art communication units On-Board-Units (OBU), where the Rocquencourt site equipped with two stationary Road-Side-Units (RSU) enabling all kind of tests and projects requirements

Below follows a more detailed description of the related research issues.

3.2.1. *Visible light and radio communication for cooperative autonomous driving*
Participants: Mohammad Abualhoul, Fawzi Nashashibi.

With the extensive development of the automobile industry and the popularity of using personal road vehicles in the last decade, both traffic accidents and road congestion levels have rapidly increased. Taking advantage of advanced wireless communications to enable C-ITS can improve both road fluidity and driver comfort. Ensuring the safety requirements has been the primary interest of the standardization societies dedicated to developing C-ITS applications, in particular with the expected significant demand for a broad range of applications targeting these strict safety requirements. RF communication technology deploying IEEE 802.11p standard for vehicular applications have been dedicated to facilitating relatively medium communication range that supports high data rate for the vehicular environment, where the technology meant to operate within the road safety requirements level.

As a consequence of the accelerated increase of the wireless-based communication devices numbers for ITS applications, the RF communication solutions are pushed toward an insatiable demand for wireless networks data access and a remarkable increase in both latency and channel congestion levels. This instability introduced more usage constraints when C-ITS is required. An example of such applications where the safety requirements and usage constraints might be strictly sharp are the convoy-based ITS applications.

This research effort contributes to the autonomous vehicular communication and urban mobility improvements. The work addresses the main radio-based V2V communication limitations and challenges for ITS hard-safety applications and intends to deploy the vehicular lighting system as a supportive communication solution for convoy-based applications as an IVC [2]-enabled autonomous vehicle. The ultimate objectives of thisresearch was to implement, validate and integrate the VLC system within the existing C-ITS architecture by developing a VLC prototype, together with sufficient hand-over algorithms enabling VLC, RF, and perception-based solutions to ensure the maximum safety requirements and the continuous information exchange between vehicles. The feasibility and efficiency of the VLC-RF system implementation and hand-over algorithms were subjects to perform practical-based in-depth investigations of the system. In addition to the improvement in road capacity by utilizing the convoy-based autonomous driving systems.

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[2]Inter Vehicle Communication

3.2.2. *Regulation study for interoperability tests for cooperative driving*
Participants: Mohammad Abualhoul, Fawzi Nashashibi.

The technological advances of autonomous and connected road vehicles have been shown an accelerating pace in the recent years. On the other hand, the regulations for autonomous, or driverless, road vehicles across Europe still deserve much attention and discussion

Therefore, RITS-Inria team plays a key element in one of the European demonstration-based projects (AUTOC-ITS), which aims to contribute to the regulation study for interoperability in the adoption of autonomous driving in European urban nodes. The regulation study done by RITS team and project partners meant to conduct a deployment of Cooperative Intelligent Transport Systems (C-ITS) in Europe by enhancing interoperability for autonomous vehicles [18]. The project activities and RITS contributions will also boost the role of C-ITS as the primary catalyst for any future implementation of autonomous driving scenarios in Europe. The final demonstration of different European partners will require the implementation and preparations of three pilots sites in three major European cities: Paris, Madrid, and Lisbon. Pilot locations in these major cities are chosen to be located along the European Atlantic Corridor for interoperability evaluation.

RITS-Inria is coordinating the French contribution by evaluating the deployment of C-ITS services in the A13-Paris, which belongs to the French part of the Atlantic Corridor.

Team Core contributions:

- Provide up to date feedback to contribute to the present EU and international regulations on autonomous vehicles.

- Build and evaluate the pilots experimentally by deploying fully autonomous vehicles and a Cooperative Intelligent Transport Systems (C-ITS).

- Define and evaluate a safety autonomous driving services, such as:
    – Roadworks warning.
    – Weather conditions.
    – Other hazardous notifications.

- Define and perform communication interoperability tests between deferent partners for different scenarios, messaging and hardware to ensure the compatibility in using the IEEE 802.11p standard.

- Study the extension of the results on large-scale deployment in other European countries.

- Contribute to the European standards organizations such as C-Roads, C-ITS platforms.

AUTOC-ITS project brings the road authorities from France, Span, and Portugal (DGT, ANSR, SANEF) and C-ITS experts from research institutes and universities (Inria, INDRA, UPM, UC, IPN) to carry out a cooperative work and contributes to the C-ITS Platform by bringing answers to the field of automation driving.

3.2.3. *V2X radio communications for road safety applications*
Participants: Mohammad Abualhoul, Fawzi Nashashibi.

The development work and generating proper components to facilitate communication requirements and to be deployed in different projects scenarios is one of the main ongoing activities by all RITS team members.

There are continuous activities on both theoretical modeling and experimental evaluation of the radio channel characteristics in vehicular networks, especially the radio quality, channel congestion, load allocations, congestion, and bandwidth availability.

Based on our previous expertise and studies, we develop mechanisms for efficient and reliable V2X communications, access point selection, handover algorithms which are especially dedicated to road safety and autonomous driving applications.

3.2.4. *Safety-critical communications in intelligent vehicular networks*
Participant: Gérard Le Lann.

Intelligent vehicular networks (IVNs) are constituents of ITS. IVNs range from platoons with a lead vehicle piloted by a human driver to fully ad-hoc vehicular networks, a.k.a. VANETs, comprising autonomous/automated vehicles. Safety issues in IVNs appear to be the least studied in the ITS domain. The focus of our work is on safety-critical (SC) scenarios, where accidents and fatalities inevitably occur when such scenarios are not handled correctly. In addition to on-board robotics, inter-vehicular radio communications have been considered for achieving safety properties. Since both technologies have known intrinsic limitations (in addition to possibly experiencing temporary or permanent failures), using them redundantly is mandatory for meeting safety regulations. Redundancy is a fundamental design principle in every SC cyber-physical domain, such as, e.g., air transportation. (Optics-based inter-vehicular communications may also be part of such redundant constructs.) The focus of our on-going work is on safety-critical (SC) communications. We consider IVNs on main roads and highways, which are settings where velocities can be very high, thus exacerbating safety problems acceptable delays in the cyber space, and response times in the physical space, shall be very small. Human lives being at stake, such delays and response times must have strict (non-stochastic) upper bounds under worst-case conditions (vehicular density, concurrency and failures). Consequently, we are led to look for deterministic solutions.

Rationale

In the current ITS literature, the term *safety* is used without being given a precise definition. That must be corrected. In our case, a fundamental open question is: what is the exact meaning of *SC communications*? We have devised a definition, referred to as space-time bounds acceptability (STBA) requirements. For any given problem related to SC communications, those STBA requirements serve as yardsticks for distinguishing acceptable solutions from unacceptable ones with respect to safety. In conformance with the above, STBA requirements rest on the following worst-case upper bounds: λ for channel access delays, and Δ for distributed inter-vehicular coordination (message dissemination, distributed agreement).

Via discussions with foreign colleagues, notably those active in the IEEE 802 Committee, we have comforted our early diagnosis regarding existing standards for V2V/V2I/V2X communications, such as IEEE 802.11p and ETSI ITS-G5: they are totally inappropriate regarding SC communications. A major flaw is the choice of CSMA/CA as the MAC-level protocol. Obviously, there cannot be such bounds as λ and Δ with CSMA/CA. Another flaw is the choice of medium-range omnidirectional communications, radio range in the order of 250 m, and interference range in the order of 400 m. Stochastic delays achievable with existing standards are just unacceptable in moderate/worst-case contention conditions. Consider the following setting, not uncommon in many countries: a highway, 3 lanes each direction, dense traffic, i.e. 1 vehicle per 12.5 m. A simple calculation leads to the following result: any vehicle may experience (destructive) interferences from up to 384 vehicles. Even if one assumes some reasonable communications activity ratio, say 25%, one finds that up to 96 vehicles may be contending for channel access. Under such conditions, MAC-level delays and string-wide dissemination/agreement delays achieved by current standards fail to meet the STBA requirements by huge margins.

Reliance on V2I communications via terrestrial infrastructures and nodes, such as road-side units or WiFi hotspots, rather than direct V2V communications, can only lead to poorer results. First, reachability is not guaranteed: hazardous conditions may develop anywhere anytime, far away from a terrestrial node. Second, mixing SC communications and ordinary communications within terrestrial nodes is a violation of the very fundamental segregation principle: SC communications and processing shall be isolated from ordinary communications and processing. Third, security: it is very easy to jam or to spy on a terrestrial node; moreover, terrestrial nodes may be used for launching all sorts of attacks, man-in-the-middle attacks for example. Fourth, delays can only get worse than with direct V2V communications, since transiting via a node inevitably introduces additional latencies. Fifth, the delivery of every SC message must be acknowledged, which exacerbates the latency problems. Sixth, availability: what happens when a terrestrial node fails?

Trying to tweak existing standards for achieving SC communications is vain. That is also unjustified. Clearly, medium-range omnidirectional communications are unjustified for the handling of SC scenarios. By definition, accidents can only involve vehicles that are very close to each other. Therefore, short-range directional communications suffice. The obvious conclusion is that novel protocols and inter-vehicular coordination

algorithms based on short-range direct V2V communications are needed. It is mandatory to check whether these novel solutions meet the STBA requirements. Future standards specifically aimed at SC communications in IVNs may emerge from such solutions.

Naming and privacy

Additionally, we are exploring the (re)naming problem as it arises in IVNs. Source and destination names appear in messages exchanged among vehicles. Most often, names are IP addresses or MAC addresses (plate numbers shall not be used for privacy reasons). A vehicle which intends to communicate with some vehicle, denoted V here, must know which name *name(V)* to use in order to reach/designate V. Existing solutions are based on multicasting/broadcasting existential messages, whereby every vehicle publicizes its existence (name and geolocation), either upon request (replying to a Geocast) or spontaneously (periodic beaconing). These solutions have severe drawbacks. First, they contribute to overloading communication channels (leading to unacceptably high worst-case delays). Second, they amount to breaching privacy voluntarily. Why should vehicles reveal their existence and their time dependent geolocations, making tracing and spying much easier? Novel solutions are needed. They shall be such that:

- At any time, a vehicle can assign itself a name that is unique within a geographical zone centered on that vehicle (no third-party involved),
- No linkage may exist between a name and those identifiers (plate numbers, IP/MAC addresses, etc.) proper to a vehicle,
- Different (unique) names can be computed at different times by a vehicle (names can be short-lived or long-lived),
- *name(V)* at UTC time t is revealed only to those vehicles sufficiently close to V at time t, notably those which may collide with V.

We have solved the (re)naming problem in string/cohort formations [43]. Ranks (unique integers in any given string/cohort) are privacy-preserving names, easily computed by every member of a string, in the presence of string membership changes (new vehicles join in, members leave). That problem is open when considering arbitrary clusters of vehicles/strings encompassing multiple lanes.

3.3. Probabilistic modeling for large transportation systems

Participants: Mohamed Hadded, Guy Fayolle, Jean-Marc Lasgouttes, Ilias Xydias.

This activity concerns the modeling of random systems related to ITS, through the identification and development of solutions based on probabilistic methods and more specifically through the exploration of links between large random systems and statistical physics. Traffic modeling is a very fertile area of application for this approach, both for macroscopic (fleet management [41], traffic prediction) and for microscopic (movement of each vehicle, formation of traffic jams) analysis. When the size or volume of structures grows (leading to the so-called "thermodynamic limit"), we study the quantitative and qualitative (performance, speed, stability, phase transitions, complexity, etc.) features of the system.

In the recent years, several directions have been explored.

3.3.1. *Traffic reconstruction*

Large random systems are a natural part of macroscopic studies of traffic, where several models from statistical physics can be fruitfully employed. One example is fleet management, where one main issue is to find optimal ways of reallocating unused vehicles: it has been shown that Coulombian potentials might be an efficient tool to drive the flow of vehicles. Another case deals with the prediction of traffic conditions, when the data comes from probe vehicles instead of static sensors.

While the widely-used macroscopic traffic flow models are well adapted to highway traffic, where the distance between junction is long (see for example the work done by the NeCS team in Grenoble), our focus is on a more urban situation, where the graphs are much denser. The approach we are advocating here is model-less, and based on statistical inference rather than fundamental diagrams of road segments. Using the Ising model or even a Gaussian Random Markov Field, together with the very popular Belief Propagation (BP) algorithm, we have been able to show how real-time data can be used for traffic prediction and reconstruction (in the space-time domain).

This new use of BP algorithm raises some theoretical questions about the ways the make the belief propagation algorithm more efficient:

- find the best way to inject real-valued data in an Ising model with binary variables [45];
- build macroscopic variables that measure the overall state of the underlying graph, in order to improve the local propagation of information [42];
- make the underlying model as sparse as possible, in order to improve BP convergence and quality [44].

3.3.2. *Exclusion processes for road traffic modeling*

The focus here is on road traffic modeled as a granular flow, in order to analyze the features that can be explained by its random nature. This approach is complementary to macroscopic models of traffic flow (as done for example in the Opale team at Inria), which rely mainly on ODEs and PDEs to describe the traffic as a fluid.

One particular feature of road traffic that is of interest to us is the spontaneous formation of traffic jams. It is known that systems as simple as the Nagel-Schreckenberg model are able to describe traffic jams as an emergent phenomenon due to interaction between vehicles. However, even this simple model cannot be explicitly analyzed and therefore one has to resort to simulation.

One of the simplest solvable (but non trivial) probabilistic models for road traffic is the exclusion process. It lends itself to a number of extensions allowing to tackle some particular features of traffic flows: variable speed of particles, synchronized move of consecutive particles (platooning), use of geometries more complex than plain 1D (cross roads or even fully connected networks), formation and stability of vehicle clusters (vehicles that are close enough to establish an ad-hoc communication system), two-lane roads with overtaking.

The aspect that we have particularly studied is the possibility to let the speed of vehicle evolve with time. To this end, we consider models equivalent to a series of queues where the pair (service rate, number of customers) forms a random walk in the quarter plane $\mathbb{Z}_+^2$.

Having in mind a global project concerning the analysis of complex systems, we also focus on the interplay between discrete and continuous description: in some cases, this recurrent question can be addressed quite rigorously via probabilistic methods.

We have considered in [39] some classes of models dealing with the dynamics of discrete curves subjected to stochastic deformations. It turns out that the problems of interest can be set in terms of interacting exclusion processes, the ultimate goal being to derive hydrodynamic limits after proper scaling. A seemingly new method is proposed, which relies on the analysis of specific partial differential operators, involving variational calculus and functional integration. Starting from a detailed analysis of the Asymmetric Simple Exclusion Process (ASEP) system on the torus $\mathbb{Z}/n\mathbb{Z}$, the arguments a priori work in higher dimensions (ABC, multi-type exclusion processes, etc), leading to systems of coupled partial differential equations of Burgers' type.

3.3.3. *Random walks in the quarter plane* $\mathbb{Z}_+^2$

This field remains one of the important *violon d'Ingres* in our research activities in stochastic processes, both from theoretical and applied points of view. In particular, it is a building block for models of many communication and transportation systems.

One essential question concerns the computation of stationary measures (when they exist). As for the answer, it has been given by original methods formerly developed in the team (see books and related bibliography). For instance, in the case of small steps (jumps of size one in the interior of $\mathbb{Z}_+^2$), the invariant measure $\{\pi_{i,j}, i, j \geq 0\}$ does satisfy the fundamental functional equation (see [2]):

$$Q(x,y)\pi(x,y) = q(x,y)\pi(x) + \widetilde{q}(x,y)\widetilde{\pi}(y) + \pi_0(x,y). \tag{1}$$

where the unknown generating functions $\pi(x,y), \pi(x), \widetilde{\pi}(y), \pi_0(x,y)$ are sought to be analytic in the region $\{(x,y) \in \mathbb{C}^2 : |x| < 1, |y| < 1\}$, and continuous on their respective boundaries.

The given function $Q(x,y) = \sum_{i,j} p_{i,j} x^i y^j - 1$, where the sum runs over the possible jumps of the walk inside $\mathbb{Z}_+^2$, is often referred to as the *kernel*. Then it has been shown that equation (1) can be solved by reduction to a boundary-value problem of Riemann-Hilbert type. This method has been the source of numerous and fruitful developments. Some recent and ongoing works have been dealing with the following matters.

- *Group of the random walk*. In several studies, it has been noticed that the so-called *group of the walk* governs the behavior of a number of quantities, in particular through its *order*, which is always even. In the case of small jumps, the algebraic curve R defined by $\{Q(x,y) = 0\}$ is either of *genus* 0 (the sphere) or 1 (the torus). In [Fayolle-2011a], when the drift of the random walk is equal to 0 (and then so is the genus), an effective criterion gives the *order* of the group. More generally, it is also proved that whenever the genus is 0, this order is infinite, except precisely for the zero drift case, where finiteness is quite possible. When the *genus* is 1, the situation is more difficult. Recently [40], a criterion has been found in terms of a determinant of order 3 or 4, depending on the arity of the group.

- *Nature of the counting generating functions*. Enumeration of planar lattice walks is a classical topic in combinatorics. For a given set of allowed jumps (or steps), it is a matter of counting the number of paths starting from some point and ending at some arbitrary point in a given time, and possibly restricted to some regions of the plane. A first basic and natural question arises: how many such paths exist? A second question concerns the nature of the associated counting generating functions (CGF): are they rational, algebraic, holonomic (or D-finite, i.e. solution of a linear differential equation with polynomial coefficients)?

  Let $f(i,j,k)$ denote the number of paths in $\mathbb{Z}_+^2$ starting from $(0,0)$ and ending at (i,j) at time k. Then the corresponding CGF

$$F(x,y,z) = \sum_{i,j,k \geq 0} f(i,j,k) x^i y^j z^k \tag{2}$$

satisfies the functional equation

$$K(x,y)F(x,y,z) = c(x)F(x,0,z) + \widetilde{c}(y)F(0,y,z) + c_0(x,y), \tag{3}$$

where z is considered as a time-parameter. Clearly, equations (2) and (1) are of the same nature, and answers to the above questions have been given in [Fayolle-2010].

- *Some exact asymptotics in the counting of walks in $\mathbb{Z}_+^2$*. A new and uniform approach has been proposed about the following problem: *What is the asymptotic behavior, as their length goes to infinity, of the number of walks ending at some given point or domain (for instance one axis)?* The method in [Fayolle-2012] works for *both* finite or infinite groups, and for walks not necessarily restricted to excursions.

3.3.4. Simulation for urban mobility

We have worked on various simulation tools to study and evaluate the performance of different transportation modes covering an entire urban area.

- Discrete event simulation for collective taxis, a public transportation system with a service quality comparable with that of conventional taxis.
- Discrete event simulation a system of self-service cars that can reconfigure themselves into shuttles, therefore creating a multimodal public transportation system; this second simulator is intended to become a generic tool for multimodal transportation.
- Joint microscopic simulation of mobility and communication, necessary for investigation of cooperative platoons performance.

These two programs use a technique allowing to run simulations in batch mode and analyze the dynamics of the system afterward.

4. Application Domains

4.1. Introduction

While the preceding section focused on methodology, in connection with automated guided vehicles, it should be stressed that the evolution of the problems which we deal with remains often guided by the technological developments. We enumerate three fields of application whose relative importance varies with time and which have strong mutual dependencies: driving assistance, cars available in self-service mode and fully automated vehicles (cybercars).

4.2. Driving assistance

Several techniques will soon help drivers. One of the first immediate goal is to improve security by alerting the driver when some potentially dangerous or dangerous situations arise, i.e. collision warning systems or lane tracking could help a bus driver and surrounding vehicle drivers to more efficiently operate their vehicles. Human factors issues could be addressed to control the driver workload based on additional information processing requirements. Another issue is to optimize individual journeys. This means developing software for calculating optimal (for the user or for the community) paths. Nowadays, path planning software is based on a static view of the traffic: efforts have to be done to take the dynamic component in account.

4.3. New transportation systems

The problems related to the abusive use of the individual car in large cities led the populations and the political leaders to support the development of public transport. A demand exists for a transport of people and goods which associates quality of service, environmental protection and access to the greatest number. Thus the tram and the light subways of VAL type recently introduced into several cities in France conquered the populations, in spite of high financial costs. However, these means of mass transportation are only possible on lines on which there is a keen demand. As soon as one moves away from these "lines of desire" or when one deviates from the rush hours, these modes become expensive and offer can thus only be limited in space and time. To give a more flexible offer, it is necessary to plan more individual modes which approach the car as we know it. However, if one wants to enjoy the benefits of the individual car without suffering from their disadvantages, it is necessary to try to match several criteria: availability anywhere and anytime to all, lower air and soils pollution as well as sound levels, reduced ground space occupation, security, low cost. Electric or gas vehicles available in self-service, as in the Praxitèle system, bring a first response to these criteria. To be able to still better meet the needs, it is however necessary to re-examine the design of the vehicles on the following points:

- ease empty car moves to better distribute them;
- better use of information systems inboard and on ground;
- better integrate this system in the global transportation system.

These systems are now operating. The challenge is to bring them to an industrial phase by transferring technologies to these still experimental projects.

4.4. Automated vehicles

The long term effort of the project is to put automatically guided vehicles (cybercars) on the road. It seems too early to mix cybercars and traditional vehicles, but data processing and automation now make it possible to consider in the relatively short term the development of such vehicles and the adapted infrastructures. RITS aims at using these technologies on experimental platforms (vehicles and infrastructures) to accelerate the technology transfer and to innovate in this field. Other application can be precision docking systems that will allow buses to be automatically maneuvered into a loading zone or maintenance area, allowing easier access for passengers, or more efficient maintenance operations. Transit operating costs will also be reduced through decreased maintenance costs and less damage to the braking and steering systems. Regarding technical topics, several aspects of Cybercars have been developed at RITS this year. First, we have stabilized a generic Cycab architecture involving Inria SynDEx tool and CAN communications. The critical part of the vehicle is using a real-time SynDEx application controlling the actuators via two Motorola's MPC555. Today, we have decided to migrate to the new dsPIC architecture for more efficiency and ease of use. This application has a second feature, it can receive commands from an external source (Asynchronously to this time) on a second CAN bus. This external source can be a PC or a dedicated CPU, we call it high level. To work on the high level, in the past years we have been developing a R&D framework called (Taxi) which used to take control of the vehicle (Cycab and Yamaha) and process data such as gyro, GPS, cameras, wireless communications and so on. Today, in order to rely on a professional and maintained solution, we have chosen to migrate to the RTMaps SDK development platform. Today, all our developments and demonstrations are using this efficient prototyping platform. Thanks to RTMaps we have been able to do all the demonstrations on our cybercars: cycabs, Yamaha AGV and new Cybus platforms. These demonstrations include: reliable SLAMMOT algorithm using 2 to 4 laser sensors simultaneously, automatic line/road following techniques, PDA remote control, multi sensors data fusion, collaborative perception via ad-hoc network. The second main topic is inter-vehicle communications using ad-hoc networks. We have worked with the EVA team for setting and tuning OLSR, a dynamic routing protocol for vehicles communications. Our goal is to develop a vehicle dedicated communication software suite, running on a specialized hardware. It can be linked also with the Taxi Framework for getting data such GPS information's to help the routing algorithm.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. *Awards*

Mohammad Abualhoul, with the paper , won the Runner-up Best Paper Award at ICVES 2018 (2018 IEEE International Conference on Vehicular Electronics and Safety, September 12-14, Madrid, Spain).

BEST PAPER AWARD:

[17]

M. ABUALHOUL, E. TALAVERA MUNOZ, F. NASHASHIBI. *The Use of Lane-Centering to Ensure the Visible Light Communication Connectivity for a Platoon of Autonomous Vehicles*, in "ICVES'2018 - 20th IEEE International Conference on Vehicular Electronics and Safety", Madrid, Spain, September 2018, https://hal.inria.fr/hal-01888549

6. New Software and Platforms

6.1. PML-SLAM

KEYWORD: Localization

SCIENTIFIC DESCRIPTION: Simultaneous Localization and Mapping method based on 2D laser data.

- Participants: Fawzi Nashashibi and Zayed Alsayed
- Contact: Fawzi Nashashibi

6.2. V2Provue

Vehicle-to-Pedestrian

FUNCTIONAL DESCRIPTION: It is a software developed for the Vehicle-to-Pedestrian (V2P) communications, risk calculation, and alarming pedestrians of collision risk. This software is made of an Android application dedicated to pedestrians and RtMaps modules for the vehicles.

On the pedestrian side, the application is relying on GPS data to localize the user and Wi-Fi communications are used to receive messages about close vehicles and send information about the pedestrian positioning. Besides, a service has been developed to evaluate the collision risk with the vehicles near the pedestrian and an HMI based on OpenStreetMap displays all the useful information such as pedestrian and vehicles localization and, collision risk.

On the vehicle side, RtMaps modules allowing V2X communications have been developed. These modules contain features such as TCP/UDP socket transmissions, broadcast, multicast, unicast communications, routing, forwarding algorithms, and application specific modules. In the V2ProVu software, a particular application module has been implemented to create data packets containing information about the vehicle state (position, speed, yaw rate,...) and the V2X communication stack is used to broadcast these packets towards pedestrians. Moreover, the V2proVu application can also receive data from pedestrians and create objects structures that can be shared with the vehicle perception tools.

- Contact: Fawzi Nashashibi

6.3. SimConVA

Connected Autonomous Vehicles Simulator

FUNCTIONAL DESCRIPTION: The software provides an interface between the network simulator ns-3 (https://www.nsnam.org/) and the modular prototyping framework RTMaps (https://intempora.com/).

This code allows to create an RTMaps component which activates and controls the ns-3 simulator. The component handles the sending and reception of data packets between ns-3 and RTMaps for each vehicle. It also handles the mobility of vehicles in ns-3 using their known position in RTMaps.

- Authors: Pierre Merdrignac, Oyunchimeg Shagdar and Jean-Marc Lasgouttes
- Contact: Jean-Marc Lasgouttes

7. New Results

7.1. Deep Reinforcement Learning for end-to-end driving

Participants: Raoul de Charette, Maximilian Jaritz, Fawzi Nashashibi.

Following the work initiated in 2017, we continued the work on end-to-end driving using with asynchronous reinforcement learning directly. The network learns to map low level control directly with RGB images. To continue previous works initiated, we have applied recent domain adaptation and evaluated our reinforcement learning (learn in a realistic car game) in open-loop on real video footage, showing promising adaptation results. New outcome also include tests on real data (web footage). This led to a publication in ICRA [25]. This research was partially funded by Valeo.

7.2. Convolutional neural networks for Semantic and Completion with Sparse and Dense Data

Participants: Raoul de Charette, Maximilian Jaritz, Fawzi Nashashibi.

Deep convolutional networks have outperform all previous techniques on most vision tasks. This is because they are able to utilize dense data and extract relationship between local information such as gradients, or high level features. However, convolutional neural networks (CNNs) require dense data and are known to fail when data is sparse. Here, we address the research problem and proposed a solution. Instead of using a sparse convolution methodology, we show that using the right architecture with a proper training strategy the network can learn sparsity invariant feature while remaining stable when dense data are present. Our architecture uses an encoder-decoder version of Mobile NasNet with skip connections. The results show that we can accomplish both data completion or semantic segmentation changing only the last layer of the network. Performance obtained were published on Kitti Benchmark and ranks among the first ones, and the methodology was published in 3DV [26]. This research was partially funded by Valeo.

7.3. Realistic Weather Augmentation for Evaluation of Bad Weather in Computer Vision

Participants: Raoul de Charette, Shirsendu Halder.

Computer vision is evaluated on extensive databases that include large number of examples and allow the ranking of algorithms. However, all databases are acquired in clear weather conditions, where the atmosphere is a transparent medium. In rain/snow/fog, when the atmosphere is filled with particles the light is refracted/reflected/diffracted and the appearance is altered. Here we propose a new research that augment existing databases with new weather or arbitrary amount. We applied it on Kitti and Cityscapes. Our approach uses an accurate understanding of physical and optics models to generate realistic rain/fog and augment existing images or sequences. This allows us to evaluate state-of-the-art vision algorithms for both object detection and semantics and quantitatively measure the effect of rain or fog on them. This research was conducted in collaboration with Jean-Francois Lalonde from Université Laval and was supported by Samuel de Champlain Quebec-France collaboration program.

7.4. Perception for Cooperative Driving

Participants: Pierre Bourre, Raoul de Charette, Carlos Flores, Renaud Poncelet, Luis Roldao, Dinh-Van Nguyen.

In the context of multiple autonomous vehicles, sharing the perception of each other allows an enriched perception of the environment. For the PACV2x FUI project, we propose a mix of vision sensors and communication exchanges is used for merging, overtaking, and other risky situations that benefit from multi perception. A speed planning algorithm as well as low level control and lidar data clustering were developed to allow a small fleet of two to three vehicles to handle such scenarios. The vehicles use communication and GPS coordinates to closely follow a planned trajectory.

7.5. A Statistical Update of Grid Representations from Range Sensors

Participants: Luis Roldao, Raoul de Charette, Anne Verroust-Blondet.

An accurate 3D model of the surrounding environment is a fundamental feature for autonomous vehicles to perform different tasks such as obstacle detection, localization and mapping. While continuous representations are widely used in the literature, we prefer to use a three dimensional discrete grid representation in this work in order to reduce memory an computational complexity. In this case, each grid cell represents the occupancy state of a portion of the environment in a probabilistic manner.

By definition, a discretized representation inhibits a completely accurate reconstruction. Therefore, grid models are unable to create a perfect model of the surroundings. In the literature, it is usually considered that within a single scan, the state of each cell is binary (free or occupied). Hence, a cell is set occupied if at least one impact occurred within, and free if it has been traversed by any ray. The problem of such an approach is that the complete state of the cell is updated from a single partial observation, neglecting the contribution of multiple measurements and their validity. Moreover, the traversed distance of the rays within each cell is usually ignored.

Towards the goal of achieving a more accurate representation, we propose a different way to update the occupancy probability of each cell according to the observations; considering the traversed distance of the rays within each cell (ray-path information), the contribution of the complete set of observations within the cell, and the density of observations that can be obtained at such cell according to its distance from the sensor. Proposed method was evaluated in both simulated and real data. Reconstruction results show an improvement on the representation of the surroundings with less occupancy state errors in the cells of the grid. Future works will include the comparison against a continuous representation to test the accuracy along with the time and computation needs for both representations.

More details can be found in [38] and [30]. This research is partially funded by AKKA Technology.

7.6. Recognizing Pedestrians using Cross-Modal Convolutional Networks

Participants: Danut-Ovidiu Pop, Fawzi Nashashibi.

This year, we have continued our research, which is based on multi-modal image fusion schemes with deep learning classification methods. We propose four different learning patterns based on Cross-Modality deep learning of Convolutional Neural Networks:

(1) a Particular Cross-Modality Learning;

(2) a Separate Cross-Modality Learning;

(3) a Correlated Cross-Modality Learning and

(4) an Incremental CrossModality Learning model.

Moreover, we also design a new variation of a Lenet architecture, which improves the classification performance. Finally, we propose to learn this model with the incremental cross-modality approach using optimal learning settings, obtained with a K-fold Cross Validation pattern. This method outperforms the state-of-the-art classifier provided with Daimler datasets on both non-occluded and partially-occluded pedestrian tasks.

7.7. Vehicle Trajectory Prediction

Participants: Kaouther Messaoud, Itheri Yahiaoui, Anne Verroust-Blondet, Fawzi Nashashibi.

In order to enhance the road safety, the first and the most important step for an effective autonomous navigation is the environment perception and surrounding objects recognition. So, advanced sensing systems are mounted in vehicles to monitor the on-road environment. One of the most challenging tasks is to understand, analyze the driving situations and make a reasonable and safe navigation decisions accordingly. Human drivers make decisions while implicitly reasoning about how neighboring drivers will move in the future. In this context, we aim to predict the motion of drivers neighboring an autonomous vehicle based on data captured using deployed sensors.

This year, we studied the state of the art approaches for trajectory and maneuver prediction. We focused on general trajectory prediction representation while considering interactions between the neighboring drivers using different types of neural networks such as recurrent and convolutional neural networks.

7.8. WiFi Fingerprinting Localization for Intelligent Vehicles in Car Park

Participants: Dinh-Van Nguyen, Raoul de Charette, Fawzi Nashashibi.

A novel method of WiFi fingerprinting for localizing intelligent vehicles in GPS-denied area, such as car parks, has been proposed. Although the method itself is a popular approach for indoor localization application, adapting it to the speed of vehicles requires different treatment. By deploying an ensemble neural network for fingerprinting classification, the method shows a reasonable localization precision at car park speed. Furthermore, a Gaussian Mixture Model (GMM) Particle Filter is applied to increase localization frequency as well as accuracy. Experiments show promising results with average localization error of 0.6m (cf. [29]).

A more complete study on the use of Wifi fingerprinting for solving the localization problem for autonomous vehicles in GPS-denied environments is presented in the thesis manuscript entitled "Wireless Sensors Networks for Indoor Mapping and Accurate Localization for Low Speed Navigation in Smart Cities" (cf. [11]).

7.9. Enhancing the Accuracy of SLAM-based Localization Systems for Autonomous Driving

Participants: Zayed Alsayed, Anne Verroust-Blondet, Fawzi Nashashibi.

Computing a reliable and accurate pose for a vehicle in any situation is one of the challenges for Simultaneous Localization And Mapping methods (SLAM) methods. Based on the probabilistic form of the SLAM solution, SLAM methods suffer from systematic errors related to the linearization of the solution models. The accuracy of the SLAM method can be improved by estimating a correction to be applied to the SLAM output based on relevant information available from the SLAM algorithm. In [20] two approaches predicting corrections to be applied to SLAM estimations are proposed:

1) The first approach is designed for 2D SLAM methods, i.e. independently of the underlying SLAM process and sensor used, where we aim to reduce the errors due to the dynamical modeling during specific maneuvers.

2) The second method is designed to handle errors related to the probabilistic formulation of Maximum Likelihood SLAM approaches, and thus it is suitable for 2D Maximum Likelihood SLAM methods (i.e. no assumptions on the sensor used).

The validity of both approaches was proved through two experiments using different evaluation metrics and using different sensor characteristics.

More detail can be found in the thesis manuscript of Zayed Alsayed entitled "Characterizing the Robustness and Enhancing the Accuracy of SLAM-based Localization Systems for Autonomous Driving" (cf. [7]).

7.10. LIDAR-based lane marking detection for vehicle localization

Participants: Farouk Ghallabi, Fawzi Nashashibi.

Accurate self-vehicle localization is an important task for autonomous driving and ADAS. Current GNSS-based solutions do not provide better than 2-3 m in open-sky environments. In order to achieve lane-level accuracy, a lane marking detection system using a multilayer LIDAR (velodyne) and a map matching algorithm has been introduced. The perception system includes three different steps: road segmentation, image construction and line detection. Our road segmentation method purely relies on geometric analysis of each layer returns. Detected lane markings are matched to a prototype third party map which was built with absolute accuracy = 5cm. The map matching algorithm is a particle filtering process that achieves lane-level accuracy (20 cm). More details are in [23]. This work has been partially funded by Renault.

7.11. Motion Planning among Highly Dynamic Obstacles

Participants: Pierre de Beaucorps, Anne Verroust-Blondet, Renaud Poncelet, Fawzi Nashashibi.

Motion planning in a dynamic environment is of great importance in many robotics applications. In the context of an autonomous mobile robot, it requires computing a collision-free path from a start to a goal among moving and static obstacles. We have introduced a framework to integrate into a motion planning method the interaction zones of a moving robot with its future surroundings, the reachable interaction sets (RIS). It can handle highly dynamic scenarios when combined with path planning methods optimized for quasi-static environments. It has been integrated with an artificial potential field reactive method and with a Bézier curve path planning. Experimental evaluations show that this approach significantly improves dynamic path planning methods, especially when the speeds of the obstacles are higher than the one of the robot (cf. [32] for more detail). This work has been partially funded by Valeo.

7.12. Control Architecture for Adaptive and Cooperative Car-Following

Participants: Carlos Flores, Fawzi Nashashibi.

The general scope of this work deals with three open challenges in the state-of-the-art of cooperative car-following systems:

1) Deal with the impact of not only communication links delays, but also heterogeneity between vehicles' dynamics in the same string. This should be targeted ensuring the gap-regulation robustness without degrading the expected performance to keep car-following benefits (individual and string stability). In particular, when a heterogeneous string is formed, the differences between vehicles dynamics introduce disturbances in the closed loop system affecting the string stability. In [22] we presented an online Cooperative Adaptive Cruise Control (CACC) feedforward adaptation with a fractional-order feedback controller for stable heterogeneous strings of vehicles. Simulations demonstrate the advantages over conventional homogeneous structures as well as system's capability to both enhance stability and guarantee string stability regardless the vehicles distribution.

2) Design a modular architecture that permits to introduce cooperative string driving in urban environments, where interaction with vulnerable road users is highly probable. In this context, a cooperative car-following/emergency braking system with prediction-based pedestrian avoidance capabilities using vehicle-to-vehicle and vehicle-to-pedestrian communication links has been proposed in [14] and validated with RITS platforms.

3) Further extend the benefits of Adaptive Cruise Control (ACC) and Cooperative Adaptive Cruise Control (CACC) applications on traffic flow and safety, having strict $\mathcal{L}_2$ string stability as a hard constraint, employing different calculus techniques for the control design task. A fractional-order-based control algorithm is employed to enhance the car-following and string stability performance for both ACC and CACC vehicle strings, including communication temporal delay effects has been presented in [15]. Simulation and real experiments have been conducted for validating the approach.

The aforementioned contributions have been developed in the framework of the VALET project ANR-15-CE22-0013. They have been also implemented in the vehicle platforms of RITS team, for the sake of validation and further demonstration of the final VALET system.

This scientific work can be found as well in the thesis manuscript of Carlos Flores entitled "Control Architecture for Adaptive and Cooperative Car-Following" (cf. [8]).

7.13. Stability analysis for controller switching in autonomous vehicles

Participants: Francisco Navas, Imane Mahtout, Fawzi Nashashibi.

This work investigates the Youla-Kucera (YK) parameterization to provide stable responses for autonomous vehicles when dynamics or environmental changes occur. This work explores the use of the YK parameterization in dynamics systems such as vehicles, with special emphasis on stability when some dynamic change or the traffic situation demands controller reconfiguration:

- YK parameterization provides all stabilizing controllers for a given plant. This is used in order to perform stable controller reconfiguration. Different YK-based control structures are obtained for dealing with problems such order complexity, plant disconnection or matrix inversability. Stability properties are preserved even if different structures are employed, but transient behavior between controllers changes depending on the employed YK-based structure. One of the structures presents the best transient behavior without oscillations, a lower order controller complexity and no need to disconnect the initial controller, which would be important if the system shutdown is very expensive, or the initial controller is part of a safety circuit [28]. This structure is used together with CACC applications improving CACC state-of-the-art. An hybrid behavior between two CACC controllers with different time gaps is explored by means of the YK parameterization, in order to avoid ACC degradation when communication link with preceding vehicle is lost. The proposed system uses YK parameterization and communication with a vehicle ahead (different from the preceding one) providing stable responses and, more interestingly, reducing intervehicle distances in comparison with an ACC degradation. A similar idea of hybrid behavior between CACC controller with different time gap is developed for entering/exiting vehicles in the string. In that case, YK parameterization is able to ensure stability of these merging/splitting maneuvers.

- Dual YK parameterization provides all the plants stabilized by a controller. This is employed for solving CL identification problems, or adaptive control solutions, which integrate identification and controller reconfiguration processes. YK-based CL identification uses classical OL identification algorithms, providing better results than if it is used alone. Results in a CACC-equipped vehicle prove how CL nature of the data affects a classical OL identification algorithm, and how dual YK parameterization helps to mitigate these effects. Finally, an adaptive control application is developed by using MMAC. Longitudinal dynamics of two vehicles in a CACC string are estimated within a model set, so the good CACC sytem can be chosen even if a heterogeneous string of vehicles is considered. Dynamics estimation results much more faster than other estimation processes in the literature.

- Different types of controllers and structures are used throughout Francisco Navas thesis ([10]), proving the adaptability of the YK parameterization to any type of controller. Simulation and experimental results demonstrate real implementation of stable controller reconfiguration, CL identification and adaptive control solutions dealing with dynamics changes or different traffic situations. The author thinks that YK is a suitable control framework able to ensure responses in autonomous driving.

- In [27] a design and implementation of a novel lateral control approach is proposed within Imane Mahtout thesis work. The control strategy is based on Youla-Kucera parametrization to switch gradually between controllers that are designed separately for big and small lateral errors. The presented approach studies the critical problem of initial lateral error in line following. It ensures smooth and stable transitions between controllers and provides a smooth vehicle response regardless of the lateral error. For an initial validation the work was tested in simulation, implementing a dynamic bicycle model. It has also been tested in real platforms implementing an electric Renault ZOE, with good results when activating the system at different lateral errors. Current work is focused on using YK-parametrization in estimating lateral vehicle dynamics.

7.14. Belief propagation inference for traffic prediction

Participant: Jean-Marc Lasgouttes.

This work [45], [44], in collaboration with Cyril Furtlehner (TAU, Inria), deals with real-time prediction of traffic conditions in a urban setting with incomplete data. The main focus is on finding a good way to encode available information (flow, speed, counts,...) in a Markov Random Field, and to decode it in the form of real-time traffic reconstruction and prediction. Our approach relies in particular on the Gaussian belief propagation algorithm.

This year, continuing our collaboration with PTV Sistema, we improved our techniques and obtained extensive results on large-scale datasets containing 250 to 2000 detectors. The results show very good ability to predict flow variables and a reasonably good performance on speed or occupancy variables. Some element of understanding of the observed performance are given by a careful analysis of the model, allowing to some extent to disentangle modelling bias from intrinsic noise of the traffic phenomena and its measurement process [35].

7.15. Large scale simulation interfacing

Participant: Jean-Marc Lasgouttes.

The SINETIC FUI project aims to build a complete simulation environment handling both mobility and communication. We are interested here in a so-called system-level view, focusing on simulating all the components of the system (vehicle, infrastructure, management center, etc.) and its realities (roads, traffic conditions, risk of accidents, etc.). The objective is to validate the reference scenarios that take place on a geographic area where a large number of vehicles exchange messages using the IEEE 802.11p protocol. This simulation tool is done by coupling the SUMO microscopic simulator and the ns-3 network simulator thanks to the simulation platform iTETRIS.

We have focused in this part of the project on how to reduce the execution time of large scale simulations. To this end, we designed a new simulation technique called Restricted Simulation Zone which consists on defining a set of vehicles responsible of sending the message and an area of interest around them in which the vehicles receive the packets [31].

7.16. Platoons Formation for autonomous vehicles redistribution

Participants: Mohamed Hadded, Jean-Marc Lasgouttes, Fawzi Nashashibi, Ilias Xydias.

In this paper, we consider the problem of vehicle collection assisted by a fleet manager where parked vehicles are collected and guided by fleet managers. Each platoon follows a calculated and optimized route to collect and guide the parked vehicles to their final destinations. The Platoon Route Optimization for Picking up Automated Vehicles problem, called PROPAV, consists in minimizing the collection duration, the number of platoons and the total energy required by the platoon leaders. We propose a formal definition of PROPAV as an integer linear programming problem, and then we show how to use the Non-dominated Sorting Genetic Algorithm II (NSGA-II), to deal with this multi-criteria optimization problem. Results in various configurations are presented to demonstrate the capabilities of NSGA-II to provide well-distributed Pareto-front solutions.

This work has been presented at ITSC 2018 conference [24].

7.17. Prediction-based handover between VLC and IEEE 802.11p for vehicular environment

Participants: Mohammad Abualhoul, Fawzi Nashashibi.

Despite years of development and deployment, the standardized IEEE 802.11p communication for vehicular networks can be pushed toward insatiable performance demands for wireless network data access, with a remarkable increase of both latency and channel congestion levels when subjected to scenarios with a very high vehicle density.

In specific hard safety applications such as convoys, IEEE 802.11p could seriously fail to meet the fundamental vehicular safety requirements. On the other hand, the advent of LED technologies has opened up the possibility of leveraging the more robust Visible Light Communication (VLC) technology to assist IEEE 802.11p and provide seamless connectivity in dense vehicular scenarios.

In this particular research, we proposed and validated a Prediction-based Vertical handover (PVHO) between VLC and IEEE 802.11p meant to afford seamless switching and ensure the autonomous driving safety requirements [19].

Algorithm validation and platoon system performance were evaluated using a specially implemented IEEE 802.11p-VLC module in the NS3 Network Simulator. The simulation results showed a speed-based dynamic redundancy before and after VLC interruptions with seamless switching. Moreover, the deployment of VLC for platoon intra-communication can achieve a 10-25% PDR gain in high-density vehicular scenarios, where the work was published in the IEEE International Conference on Intelligent Transportation Systems 2018.

7.18. Lane-Centering to Ensure the Visible Light Communication (VLC) Connectivity for a Platoon of Autonomous Vehicles

Participants: Mohammad Abualhoul, Fawzi Nashashibi.

VLC technology limitations were defined and supported by different solutions proposals to enhance the crucial alignment and mobility limitations. In this research [17], we proposed the incorporation of the VLC technology and a Lane-Centering (LC) technique to assure the VLC-connectivity by keeping the autonomous vehicle aligned to the lane center using vision-based lane detection in a convoy-based formation. Such combination can ensure the optical communication connectivity. This contribution by RITS-Team won the best paper award during the ICVES conference.

The system performance and evaluation showed that ss soon as the road lanes are detectable, the evaluated results showed stable behavior independently from the inter-vehicle distances and without the need for any exchanged information of the remote vehicles. Further investigations are to be carried-out in this direction.

7.19. Cyberphysical Constructs for Next-Gen Vehicles and Autonomic Vehicular Networks

Participant: Gérard Le Lann.

Behaviors of Connected Automated Vehicles (CAVs) rest on robotics capabilities (sensors, motion control laws, actuators) and wireless radio communications. Reduction of non-harmful crashes and fatalities despite higher vehicular density (safety and efficiency properties) is a fundamental objective, whatever the SAE automated driving levels considered (use cases).

Based on "hard sciences", onboard robotics capabilities designed so far are satisfactory for numerous settings, to the exception of non-line-of-sight scenarios. That is the rationale for wireless radio communications. Over the years, a growing fraction of the scientific community has been questioning the adequacy of current IEEE and ETSI standards aimed at automotive wireless communications, herein referred to as wave protocols (wireless access in vehicular environment) for convenience.

Analyses based on well-known results in various areas such as life/safety-critical systems, distributed algorithms, dependable real-time computing, ad hoc mobile networking, and cyber-physics (to name a few) come to the conclusion that wave protocols do not meet essential requirements regarding safety, efficiency, privacy or cybersecurity (SPEC). These conclusions are based on scientific demonstrations. Notably, wave protocols rest on intuitive designs (no proofs, only simulations or experimental testing) that violate well-known impossibility results in asynchronous or synchronous systems. It follows that future vehicles shall be commanded and controlled by onboard robotics supplemented with wireless communication capabilities other than wave protocols. These vehicles are referred to as Next-Gen Vehicles (NGVs) in order to avoid confusion with CAVs.

That wave solutions are far from being convincing is at the core of the recommendations issued at the EU level (the latest WG29 resolution). Moreover, the important question of how to instantiate the EU GDPR directive in future CAVs is left unanswered, despite the fact that it is possible (proofs provided) to achieve safety and privacy jointly. Preliminary results for NGVs have appeared in [34].

The work reported herein, started in 2017 along with international researchers, aims at specifying solutions to the SPEC problem, considering self-organizing and self-healing Autonomic Vehicular Networks (AVNs) of NGVs. Parallel to this, risks of privacy breaches and cyberattacks proper to wave solutions have been exposed to the public via invited interventions and presentations.

An issue not very well addressed so far is to which extent robotics and computer science supplement each other. The cyber-physical perspective is essential to formulate a coherent vision. In cyber space and in physical space, safety has to do with resource sharing. Deadlock-free and fair resource sharing in systems of concurrent processes has been a major topic in computer science for more than 50 years. Asphalt (2D systems), asphalt and air space (3D systems) are the shared resources of interest in the physical space.

As is well known, there are three classes of algorithmic solutions: detection-and-recovery, prevention, avoidance. The former class is inapplicable (one cannot "roll back an accident"). Prevention is aimed at prohibiting the emergence of hazardous (no safety) or deadlock-prone (no safety, no efficiency) conditions. Solutions are the province of distributed algorithms (computer science). Avoidance is relied on for maintaining non-hazardous conditions while making progress (also, in case some of the assumptions that underlie prevention schemes would be violated). Solutions are the province of automation control (linear/non-linear dynamics).

Prevention and avoidance schemes are needed, put in action as follows: NGVs run (cyber) distributed agreement algorithms in order to preclude the emergence of hazardous conditions, prior to executing physical motions (collision-free trajectories), which motions are made feasible thanks to prevention schemes. This is how computer science and robotics can be "married" consistently: with prevention schemes, one achieves proactive safety, and with avoidance schemes, one achieves reactive safety (both types are needed).

NGVs and AVNs are life/safety-critical cyber-physical systems. Consequently, correct solutions to the SPEC problem are based on cyber-physical constructs endowed with appropriate intrinsic properties. We have devised the cell and the cohort constructs, which rest on the obvious observation according to which only vehicles sufficiently close to each other may experience a collision. Time-bounded ultra-fast message-passing and inter-vehicular coordination can be achieved within these constructs thanks to very short-range radio and optical communications, as well as deterministic protocols (MAC protocols in particular) and distributed algorithms (dissemination, approximate agreement, and consensus). Analytical expressions of upper bounds for message-passing and inter-vehicular coordination are established for worst-case conditions, such as contention and failures, message losses in particular. We have shown that these solutions can sustain message loss frequencies an order of magnitude higher than frequencies beyond which none of the wave protocols could work.

We have defined the concept of cyberphysical levels, which are orthogonal to SAE automated driving levels. Joining a cohort longitudinally or laterally (which implies a lane change) is conditioned on a number of criteria, such as cyberphysical levels, NGV sizes, and proof of authentication (requestor's name must be a certified pseudonym).

Naming raises open problems in spontaneous mobile open systems, such as AVNs. Privacy-preserving naming is even more complex. The "longitudinal privacy-preserving naming" problem is solved with the cohort construct. The "lateral privacy-preserving naming" problem which arises with NGVs members of a cell or that circulate in adjacent cohorts has solutions based on combined optical and radio communications.

Novel deterministic time-bounded MAC protocols at the core of distributed coordination algorithms are needed to solve the open problem of safe entrances into unsignalized intersections of arbitrary topologies (any number of arterials, any number of lanes per arterial) in the presence of noisy radio channels. This problem has been solved with CSMA-CD/DCR (deterministic collision resolution) MAC protocols.

7.20. Functional equations

Participant: Guy Fayolle.

The article [13] presents functional equations (involving one or two complex variables) as an Important analytic method in stochastic modelling and in combinatorics.

7.21. Optimization of test case generation for ADAS via Gibbs sampling algorithms

Participant: Guy Fayolle.

Validating Advanced Driver Assistance Systems (ADAS) is a strategic issue, since such systems are becoming increasingly widespread in the automotive field.

But ADAS validation is a complex issue, particularly for camera based systems, because these functions may be facing a very high number of situations that can be considered as infinite. Building at a low cost level a sufficiently detailed campaign is thus very difficult. Indeed, test case generation faces the crucial question of *inherent combinatorial explosion*. An important constraint is to generate *almost all* situations in the most economical way. This task, in general, can be considered from two points of view: deterministic via binary search trees, or stochastic via Markov chain Monte Carlo (MCMC) sampling. We choose the latter probabilistic approach described below, which in our opinion seems to be the most efficient one. Typically, the problem is to produce samples of large random vectors, the components of which are possibly dependent and take a finite number of values with some given probabilities. The following flowchart is proposed.

1. In a first step, starting from the simulation graph generated by the toolboxes of MATLAB, we construct a so-called *Markov Random Field (MRF)* . When the parameters are locally dependent, this can be achieved from the user's specifications and by a systematic application of Bayes' formula.

2. Then, to cope with the combinatorial explosion, test cases are produced by implementing (and comparing) various *Gibbs samplers*, which are fruitfully employed for large systems encountered in physics. In particular, we strive to make a compromise between the convergence rate toward equilibrium, the percentage of generated duplicates and the path coverage, recalling that the speed of convergence is exponential, a classical property deduced from the general theory of Markov chains.

3. The problem of generating rare events by mixing Gibbs samplers, Large Deviation Techniques (LDT) and cross-entropy method a work in progress.

The French car manufacturer *Groupe PSA* shows a great interest in these methods and has established a contractual collaboration involving ARMINES-Mines ParisTech (Guy Fayolle as associate researcher) and Can Tho University in Vietnam (Pr. Van Ly Tran).

7.22. Random walks in orthants and lattice path combinatorics

Participant: Guy Fayolle.

In the second edition of the book [2], original methods were proposed to determine the invariant measure of random walks in the quarter plane with small jumps (size 1), the general solution being obtained via reduction to boundary value problems. Among other things, an important quantity, the so-called *group of the walk*, allows to deduce theoretical features about the nature of the solutions. In particular, when the *order* of the group is finite and the underlying algebraic curve is of genus 0 or 1, necessary and sufficient conditions have been given for the solution to be rational, algebraic or D-finite (i.e. solution of a linear differential equation). In this framework, number of difficult open problems related to lattice path combinatorics are currently being explored, in collaboration with A. Bostan and F. Chyzak (project-team SPECFUN, Inria-Saclay), both from theoretical and computer algebra points of view: concrete computation of the criteria, utilization of differential Galois theory, genus greater than 1 (i.e. when some jumps are of size ≥ 2), etc. A recent topic of future research deals with the connections between simple product-form stochastic networks (so-called *Jackson networks*) and explicit solutions of functional equations for counting lattice walks.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

Valeo Group: a very strong partnership is under reinforcement between Valeo and Inria. Several bilateral contracts were signed to conduct joint works on Driving Assistance, some of which Valeo is funding. This joint research includes:

- The PhD thesis of Pierre de Beaucorps under the framework of Valeo project "Daring"

- A CIFRE like PhD thesis is ongoing between Valeo and Inria (Maximilian JARITZ), dealing with multisensor processing and learning techniques for free navigable road detection.
- Valeo is currently a major financing partner of the "GAT" international Chaire/JointLab in which Inria is a partner. The other partners are: UC Berkeley, Shanghai Jiao-Tong University, EPFL, IFSTTAR, MPSA (Peugeot-Citroën) and SAFRAN.
- Technology transfer is also a major collaboration topic between RITS and Valeo as well as the development of a road automated prototype.
- Finally, Inria and Valeo are partners of the PIA French project CAMPUS (Connected Automated Mobility Platform for Urban Sustainability) including SAFRAN, Invia and Gemalto. The aim of the project is the development of autonomous vehicles and the realization of two canonical uses-cases on highways and urban like environments.

Renault Group: Collaboration between Renault and RITS re-started in 2016. Different research teams in Renault are now working separately with RITS on different topics.

- A CIFRE like PhD thesis is ongoing between Renault and Inria (Farouk GHALLABI) The thesis deals with the accurate localization of an autonomous vehicle on a highway using mainly on-board low-cost perception sensors.
- Another CIFRE PhD thesis is ongoing since November 2017 (Imane MAHTOUT).

AKKA Technologies: Collaboration with AKKA since 2012 (for the Link & Go prototype).

- Inria and AKKA Technologies are partners in the VALET projects (ANR projects).
- A CIFRE PhD thesis (Luis ROLDAO) dealing with 3D-environment modeling for autonomous vehicles begun in October 2017.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR

9.1.1.1. VALET

>Title: Redistribution automatique d'une flotte de véhicules en partage et valet de parking
>
>Instrument: ANR
>
>Duration: January 2016 - December 2018
>
>Coordinator: Fawzi Nashashibi
>
>Partners: Inria, Ecole Centrale de Nantes (IRCCyN), AKKA Technologies
>
>Inria contact: Fawzi Nashashibi
>
>Abstract: The VALET project proposes a novel approach for solving car-sharing vehicles redistribution problem using vehicle platoons guided by professional drivers. An optimal routing algorithm is in charge of defining platoons drivers' routes to the parking areas where the followers are parked in a complete automated mode. The main idea of VALET is to retrieve vehicles parked randomly on the urban parking network by users. These parking spaces may be in electric charging stations, parking for car sharing vehicles or in regular parking places. Once the vehicles are collected and guided in a platooning mode, the objective is then to guide them to their allocated parking area or to their respective parking lots. Then each vehicle is assigned a parking place into which it has to park in an automated mode.

9.1.1.2. Hianic

>Title: navigation autonome dans les foules inspirée par les humains (Human Inspired Autonomous Navigation In Crowds)

Instrument: ANR

Duration: January 2018 - December 2020

Coordinator: Anne Spalanzani (Inria Rhône-Alpes, Chroma research team)

Partners: Inria Rhône-Alpes, Inria Paris, LIG Laboratoire d'Informatique de Grenoble, LS2N - ECN Laboratoire des Sciences du Numérique de Nantes

Inria contact: Fawzi Nashashibi

Abstract: The HIANIC project will try to address some problems that will arise when these cars are mixed with pedestrians. The HIANIC project will develop new technologies in term of autonomous navigation in dense and human populated traffic. It will explore the complex problem of navigating autonomously in shared-space environments, where pedestrians and cars share the same environment.

Such a system will contribute both to urban safety and intelligent mobility in "shared spaces". Negotiation will help to avoid frozen situations increasing the vehicle's reactivity and optimizing the navigable space. Negotiation, Human-Aware Navigation and Communication will contribute to a better public acceptance of such autonomous systems and facilitate their penetration in the transportation landscape.

9.1.2. FUI

9.1.2.1. Sinetic

Title: Système Intégré Numérique pour les Transports Intelligents Coopératifs

Instrument: FUI

Duration: December 2014 - January 2018

Coordinator: Thomas Nguyen (Oktal)

Partners: Oktal, ALL4TEC, CIVITEC, Dynalogic, Inria, EURECOM, Renault, Armines, IFSTTAR, VEDECOM

Inria contact: Jean-Marc Lasgouttes

Abstract: The purpose of the project SINETIC is to create a complete simulation environment for designing cooperative intelligent transport systems with two levels of granularity: the system level, integrating all the components of the system (vehicles, infrastructure management centers, etc.) and its realities (terrain, traffic, etc.) and the component-level, modeling the characteristics and behavior of the individual components (vehicles, sensors, communications and positioning systems, etc.) on limited geographical areas, but described in detail.

9.1.2.2. PAC V2X

Title: Perception augmentée par coopération véhicule avec l'infrastructure routière

Instrument: FUI

Duration: September 2016 - August 2019

Coordinator: SIGNATURE Group (SVMS)

Partners: DigiMobee, LOGIROAD, MABEN PRODUCTS, SANEF, SVMS, VICI, Inria, VEDE-COM

Inria contact: Raoul de Charette

Abstract: The objective of the project is to integrate two technologies currently being deployed in order to significantly increase the time for an automated vehicle to evolve autonomously on European road networks. It is the integration of technologies for the detection of fixed and mobile objects such as radars, lidars, cameras ... etc. And local telecommunication technologies for the development of ad hoc local networks as used in cooperative systems.

9.1.3. Competitivity Clusters

RITS team is a very active partner in the competitivity clusters, especially MOV'EO and System@tic. We are involved in several technical committees like the DAS SUR of MOV'EO for example.

RITS is also the main Inria contributor in the VEDECOM institute (IEED). VEDECOM financed the PhD theses of Mr. Fernando Garrido and Mr. Zayed Alsayed.

9.2. European Initiatives

9.2.1. FP7 & H2020 Projects

9.2.1.1. AUTOCITS

Title: AUTOCITS Regulation Study for Interoperability in the Adoption of Autonomous Driving in European Urban Nodes

Program: CEF- TRANSPORT Atlantic corridor

Duration: November 2016 - March 2019

Coordinator: Indra Sistemas S.A. (Spain)

Partners: Indra Sistemas S.A. (Spain); Universidad Politécnica de Madrid (UPM), Spain; Dirección General de Tráfico (DGT), Spain; Inria (France); Instituto Pedro Nunes (IPN), Portugal; Autoridade Nacional de Segurança Rodoviária (ANSR), Portugal; Universidade de Coimbra (UC), Portugal.

Inria contact: Fawzi Nashashibi, Mohammad Abualhoul

Abstract: The aim of the Study is to contribute to the deployment of C-ITS in Europe by enhancing interoperability for autonomous vehicles as well as to boost the role of C-ITS as catalyst for the implementation of autonomous driving. Pilots will be implemented in 3 major Core Urban nodes (Paris, Madrid, Lisbon) located along the Core network Atlantic Corridor in 3 different Member States. The Action consists of Analysis and design, Pilots deployment and assessment, Dissemination and communication as well as Project Management and Coordination.

9.2.2. Collaborations with Major European Organizations

RITS is member of the **euRobotics AISBL** (Association Internationale Sans But Lucratif) and the Leader of "People transport" Topic. This makes from Inria one of the rare French robotics representatives at the European level. See also: http://www.eu-robotics.net/

RITS is a full partner of **VRA – Vehicle and Road Automation**, a support action funded by the European Union to create a collaboration network of experts and stakeholders working on deployment of automated vehicles and its related infrastructure. VRA project is considered as the cooperation interface between EC funded projects, international relations and national activities on the topic of vehicle and road automation. It is financed by the European Commission DG CONNECT and coordinated by ERTICO – ITS Europe. See also: http://vra-net.eu/

9.3. International Initiatives

9.3.1. Inria International Partners

9.3.1.1. Informal International Partners

RITS has signed 3 MoU with the following international laboratories:

- Vehicle Dynamics and Control Laboratory, Seoul National University (SNU), S. Korea: international cooperation agreement for Graduate-Level Academic and Research Collaboration
- MICA Lab, Hanoi University of Science and Technology, Vietnam: cooperation agreement for research collaboration and PhD students co-supervision
- Integrated Industrial Design Lab (INDEL) of the Department of Product and Systems Design Engineering, University of the Aegean, Greece: international cooperation agreement for Graduate-Level Academic and Research Collaboration

9.3.2. Participation in International Programs

Samuel de Champlain Québec-France collaboration program: "Vision par ordinateur en conditions difficiles", cooperation between Raoul de Charette and Jean-François Lalonde from Laval University.

9.4. International Research Visitors

9.4.1. Visits of International Scientists

Jean-François Lalonde from Laval University in October 2018 within the framework of Samuel de Champlain Québec-France collaboration program.

9.4.1.1. Internships

> Shirsendu Halder, June-December 2018.
>
> Nabila Arib, April-September 2018

9.4.2. Visits to International Teams

9.4.2.1. Research Stays Abroad

Maximilian Jaritz was at UC San Diego, visiting SU Lab directed by Hao Su, from October 1st 2018 to February 15th 2019.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

> Mohammad Abualhoul and Fawzi Nashashibi: chairs and co-organizers of the 1st CA2V workshop at the IEEE VTC'18 conference, Porto (Portugal), June 2018.
>
> Fawzi Nashashibi and Mohammad Abualhoul: chairs and co-organizers of the CA2V workshop at the IEEE ICVES'18 conference, Madrid (Spain), September 2018.
>
> Fawzi Nashashibi: chair of the AUTOCITS international workshop ob connected and autonomous vehicles, December 13, Paris, France.

10.1.1.2. Member of the Organizing Committees

> Fawzi Nashashibi was member of the organizing committee of the IEEE/RSJ IROS 2018 Autonomous Driving Events including: PPNIV Workshop, Round table and Autonomous vehicle on-site demonstrations.
>
> Fawzi Nashashibi was member of the Steering Committee of the IEEE Global Communications Conference, 9-13 December 2018, Abu Dhabi, UAE.

10.1.2. Scientific Events Selection

> Jean-Marc Lasgouttes: co-organizer of the Symposium "Large Random Networks and Constrained Random Walks" in honor of the 75th birthday of Guy Fayolle, Dijon (France), August 27–28.

10.1.2.1. Chair of Conference Program Committees

> Raoul de Charette: program chair of Workshop 'Real-World Challenges for Robotic Vision' CVPR 2018 (CVPRW).

10.1.2.2. Member of the Conference Program Committees

> Raoul de Charette: program committee member of 'Conférence Française de Photogrammétrie et de Télédétection' (CFPT).

Fawzi Nashashibi : co-organizer of the breakout session *Artificial Intelligence and Deep Machine Learning Tools and Algorithms for Automated Vehicles: The State of the Art and Practice* at the Automated Vehicles Symposium, San Francisco (USA), 9-12 July, 2018.

10.1.2.3. Reviewer

Mohammad Abualhoul: *IEEE ITS 2018*, *IEEE IV 2018*, *IEEE ICVES 2018*, *TRA 2018*.

Raoul de Charette: *CVPR 2018*, *ACCV 2018*, *IEEE ICRA 2018*, *CVPR Workshop 2018*, *IEEE IV 2018*.

Jean-Marc Lasgouttes: *IEEE ITSC 2018*.

Fawzi Nashashibi : *IEEE ICRA 2018*, *IEEE IROS 2018*, *IEEE IV 2018*, *IEEE ITSC 2018*, *IEEE ICARCV 2018*, *IEEE VTC 2018*, *IEEE ICVES 2018*

Anne Verroust-Blondet: *IEEE IV 2018*, *IEEE ITSC 2018*, *IEEE ICARCV 2018*.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

Guy Fayolle: associate editor of the journal *Markov Processes and Related Fields*.

Fawzi Nashashibi: associate editor of the journal *IEEE Transactions on Intelligent Vehicles*, associate editor of the journal *IEEE Transactions on Intelligent Transportation Systems*.

Anne Verroust-Blondet: associate editor of the journal *The Visual Computer*.

10.1.3.2. Reviewer - Reviewing Activities

Raoul de Charette: *IEEE Transactions on Intelligent Transportation Systems*

Guy Fayolle: *AAP, MPRF, PTRF, QUESTA, European Journal of Combinatorics, JSP, Physica A, Springer Science*.

Jean-Marc Lasgouttes: *IEEE Transactions on Intelligent Transportation Systems*

Fawzi Nashashibi: *IEEE Transactions on Intelligent Transportation Systems*, *IEEE Transactions on Intelligent Vehicles*, *Transportation Research Part C*.

Anne Verroust-Blondet: *IEEE Transactions on Intelligent Vehicles*

10.1.4. Invited Talks

Mohammad Abualhoul: keynote speaker in ICVES-CA2V-2018 Worshop in Madrid, June 2018.

Raoul de Charette: public presentation at BNF Paris on Artificial Intelligence (2018-10-08).

Guy Fayolle: guest speaker at the conference *Grands réseaux aléatoires et marches contraintes*, held at the University of Bourgogne, Dijon, 27-28th August 2018, http://www.lmpt.univ-tours.fr/ConferenceGuyFayolle75/.

Guy Fayolle: four long talks on topics related to the book [2] at the working group GTMA (http://divizio.joomla.com/seminaires-et-gdt/11-groupe-de-travail-autour-des-marches-dans-le-quart-de-plan).

Gérard Le Lann: "Conduite automatisée, cyber-sécurité et enjeux de société", Espace des Sciences, Rennes, April 2018.

Gérard Le Lann: "Future Directions in Autonomic Vehicular Networks", IEEE & IFIP Med-Hoc-Net Workshop, Capri, Italy, June 2018.

Gérard Le Lann: "Future Directions in Connected Autonomous Vehicles and Autonomic Vehicular Networks", ATOS Worldwide Annual TechForum, Seclin, July 2018.

Gérard Le Lann: "Future Directions in Connected Autonomous Vehicles and Autonomic Vehicular Networks", CNIL, Paris, September 2018.

Gérard Le Lann: "Safety, Privacy and Cybersecurity in Future Vehicular Networks", AutoCITS Workshop, Inria Paris, December 2018.

Fawzi Nashashibi: keynote speaker on *Scientific and technical challenges of autonomous navigation for connected autonomous vehicles* in ICVES-CA2V-2018 Worshop in Madrid, June 2018.

Fawzi Nashashibi: keynote speaker on *Autonomous vehicles in smart cities: the next challenges* in PAMS international conference, Pangyo (S. Korea), 15-16 November 2018.

Fawzi Nashashibi: keynote and Round table speaker on *Scientific and technical challenges of autonomous navigation for connected autonomous vehicles* at the International Conference on Mobility Challenges, Gif-sur-Yvette (France), 6-7 December 2018.

Fawzi Nashashibi: keynote on *Evolution and challenges of mobility with the increased introduction of artificial intelligence*, at the TOTAL AI FOR LEADERS PROGRAM, Paris (France), March 19, 2018.

Fawzi Nashashibi: keynote on the *Challenges et opportunities of autonomous mobility in smart cities*, in the working day on Intelligent Mobility, organized by TECNALIA, Madrid (Spain), February 2018.

10.1.5. Scientific Expertise

Guy Fayolle is scientific advisor and associate researcher at the *Robotics Laboratory of Mines ParisTech*. He is also collaborating member of the research-team SPECFUN at Inria-Saclay.

Jean-Marc Lasgouttes is member of the *Conseil Académique* of Université Paris-Saclay.

Gérard Le Lann: contributions to *Report on Safer Roads with Automated Vehicles ?*, International Transportation Forum, OECD, April 2018, 45 p. [3]

Fawzi Nashashibi is an associate researcher at the *Robotics Laboratory, Mines ParisTech*. He is an evaluator/reviewer of European H2020 projects.

10.1.6. Research Administration

Jean-Marc Lasgouttes is a member of the *Comité Technique Inria*.

Guy Fayolle is a member of the working group IFIP WG 7.3.

Fawzi Nashashibi is a member of the international Automated Highway Board Committee of the TRB (AHB30). He is a member of the Board of Governors of the VEDECOM Institute representing Inria and of the Board of Governors of MOV'EO Competitiveness cluster representing Inria.

Anne Verroust-Blondet is the scientific correspondent of the European affairs and of the International Partnerships for Inria Paris, member of the COST-GTRI committee at Inria (Committee in charge of the evaluation of international projects) and mamber of the "emplois scientifiques" committee of Inria Paris.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence: Fawzi Nashashibi, "Programmation avancée", 84h, L1, Université Paris-8 Saint-Denis, France.

Master: Carlos Flores and Anne Verroust-Blondet, "Le véhicule autonome. Présentation des recherches de l'équipe-projet RITS",1.5 h, 2nd year, Ecole des Ponts ParisTech, France, September 2018.

Master: Jean-Marc Lasgouttes, "Analyse de données", 54h, second year of Magistère de Finance (M1), University Paris 1 Panthéon Sorbonne, France.

Master: Jean-Marc Lasgouttes, "Analyse de données", 52.5h, Master 1 SIC APP, University Paris 1 Panthéon Sorbonne, France.

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[3] https://www.itf-oecd.org/sites/default/files/docs/safer-roads-automated-vehicles.pdf

Master: Fawzi Nashashibi, "Image synthesis and 3D Infographics", 12h, M2, INT Télécom Sud-Paris.

Master: Fawzi Nashashibi, "Obstacle detection and Multisensor Fusion", 4h, M2, INSA de Rouen.

Master: Fawzi Nashashibi, "Perception and Image processing for Mobile Autonomous Systems", 12h, M2, University of Evry.

Master: Renaud Poncelet, "Mécatronique fondamentale", 64h, 4rd year, Pôle Universitaire Léonard de Vinci, Paris La Défense, France.

Doctorat: Jean-Marc Lasgouttes, "Analyse de données fonctionnelles", 31.5h, Mastère Spécialisé "Expert en sciences des données", INSA-Rouen, France

10.2.2. Supervision

PhD: Zayed Alsayed,"Characterizing the Robustness and Enhancing the Accuracy of SLAM-based Localization Systems for Autonomous Driving", Télécom ParisTech, June 2018, supervisor: Anne Verroust-Blondet, co-supervisors: Fawzi Nashashibi, Guillaume Bresson.

PhD: Carlos Flores, "Control Architecture for Adaptive and Cooperative Car-Following", Mines ParisTech, PSL Research University, December 2018, supervisor: Fawzi Nashashibi, co-supervisor: Vicente Milanés.

PhD: Fernando Garrido, "Two-staged local trajectory planning based on optimal pre-planned curves interpolation for human-like driving in urban areas" , Mines ParisTech, PSL Research University, December 2018, supervisor: Fawzi Nashashibi, co-supervisors: Vicente Milanés, Joshué Pérez.

PhD: Francisco Navas, "Stability analysis for controller switching in autonomous vehicles", Mines ParisTech, , PSL Research University, November 2018, supervisor: Fawzi Nashashibi, co-supervisor: Vicente Milanés.

PhD: Dinh-Van Nguyen, "Wireless Sensors Networks for Indoor Mapping and Accurate Localization for Low Speed Navigation in Smart Cities", Mines ParisTech, , PSL Research University, December 2018, supervisor: Fawzi Nashashibi, co-supervisor: Eric Castelli.

PhD in progress: Pierre de Beaucorps, "Autonomous vehicle: behavior prediction and Interaction with road users", UPMC Sorbonne University, January 2016, supervisor: Anne Verroust-Blondet, co-supervisor: Fawzi Nashashibi.

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PhD in progress: Maximilian Jaritz, "Perception multi-capteur pour la conduite autonome grâce à l'apprentissage profond", Mines ParisTech, PSL Research University, January 2017, supervisor: Fawzi Nashashibi, co-supervisor: Raoul de Charette.

PhD in progress: Danut-Ovidiu Pop, "Deep learning techniques for intelligent vehicles", INSA Rouen, May 2016, supervisor: Abdelaziz Bensrhair, co-supervisor: Fawzi Nashashibi.

PhD in progress: Imane Matout, "Estimation de l'intention des véhicules pour la prise de décision et le contrôle sans faille en navigation autonome", Mines ParisTech, PSL Research University, December 2017, supervisor: Fawzi Nashashibi, co-supervisor: Vicente Milanés.

PhD in progress: Kaouther Messaoud, "Détermination des manoeuvres et des intentions des véhicules avoisinant un véhicule autonome", UPMC Sorbonne University, October 2017, supervisor: Anne Verroust-Blondet, co-supervisors: Fawzi Nashashibi, Itheri Yahiaoui.

PhD in progress: Luis Roldao, "Modélisation 3D de l'environnement et de la manoeuvrabilité d'un véhicule", UPMC Sorbonne University, October 2017, supervisor: Anne Verroust-Blondet, co-supervisor: Raoul de Charette.

Starting PhD: Renaud Poncelet, "Navigation autonome en présence d'obstacles fortement dynamiques au mouvement incertain", UPMC Sorbonne University, September 2018, supervisor: Anne Verroust-Blondet, co-supervisor: Fawzi Nashashibi.

10.2.3. Juries

Fawzi Nashashibi was a jury member of the PhD thesis of Mr. Laurent Delobel - *Agrégation d'Information Pour la Localisation d'un Robot Mobile sur une Carte Imparfaite* -, Université Clermont-Auvergne, Clermont-Ferrand, 16 February 2018.

Fawzi Nashashibi was a reviewer of the PhD thesis of Mr. Yrvann Emzivat *Safety System Architecture for the Design of Dependable and Adaptable Autonomous Vehicles* -, Université Bretagne Loire, Nantes (France), 30 May 2018.

Fawzi Nashashibi was a jury member of the PhD thesis of Mr. Aymeric Dujardin - *Détection d'obstacles par stéréovision en environnement non structuré* -, Normandie Université, Saint-Etienne-du-Rouvray (France), 03 July 2018.

Fawzi Nashashibi participated, as examiner and president, to the HdR committee of Oyunchimeg Shagdar *Optimizing Wireless Communications in Dense Mobile Environments*, Université de Versailles Saint-Quentin-en-Yvelines, 6 September 2018.

Anne Verroust-Blondet was a reviewer of the PhD thesis of Sarah Bertrand - *Analyse d'images pour l'identification multi-organes d'espèces végétales*, Université Lyon 2, 10 December 2018.

Anne Verroust-Blondet was a jury member of the PhD thesis of Dai-Duong Nguyen - *A vision system based real-time SLAM application*, Université Paris-Saclay, 7 December 2018.

10.3. Popularization

10.3.1. Internal or external Inria responsibilities

Fawzi Nashashibi was the coordinator of the Inria Livre Blanc "Véhicules autonomes et connectés, les défis actuels et les voies de recherche" [4].

10.3.2. Articles and contents

A few press interviews and popular science was done in 2018.

- In books/journals/radios for the general public:

Raoul de Charette was interviewed by A. Devillard for:

- *Pour la voiture autonome, l'algorithme d'apprentissage qui ne s'entraîne pas* [5], Science et Avenir, 2018-03-18;

- *Les failles de la voiture autonome* [6], Sciences et Avenir, 2018-04-26;

Raoul de Charette and Fawzi Nashashibi were interviewed by M. Moragues for *[Infographie] L'intelligence artificielle n'est pas un as du volant* [7], L'Usine Nouvelle, 2018-09-23;

Raoul de Charette was interviewed for Sciences et Avenir, *La voiture autonome en quête de la "vision" parfaite*, 2018-09-27;

Raoul de Charette and Fawzi Nashashibi were interviewed for Challenges, *L'intelligence artificielle bute sur la sécurité routière*, 2018-10-04;

Raoul de Charette was interviewed for Radio France Internationale, 2018-03-30;

Fawzi Nashashibi was interviewed for La Tribune, *Ce que l'IA change dans l'auto : l'ère de la voiture autonome* [8], 2018-05-02;

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[5] https://www.sciencesetavenir.fr/high-tech/pour-la-voiture-autonome-un-algorithme-d-apprentissage-qui-ne-s-entraine-pas_122033
[6] https://www.sciencesetavenir.fr/high-tech/transports/les-failles-de-la-voiture-autonome_123502
[7] https://www.usinenouvelle.com/editorial/infographie-l-intelligence-artificielle-n-est-pas-un-as-du-volant.N742309
[8] https://www.latribune.fr/entreprises-finance/industrie/automobile/ce-que-l-ia-change-dans-l-auto-l-ere-de-la-voiture-autonome-776767.html

Fawzi Nashashibi was interviewed by Dominique Filippone for *Voitures autonomes : Pas avant 2040 en France selon l'Inria* [9], Le Monde Informatique, 2018-05-15;

Fawzi Nashashibi was interviewed by Loup Besmond de Senneville for *Les recommandations des chercheurs pour l'éthique des voitures autonomes* [10], La Croix, 2018-05-18;

Fawzi Nashashibi was interviewed by Frank Niedercorn for *Fawzi Nashashibi : "Il y a encore bien des obstacles pour le véhicule autonome"* [11], Les Echos, 2018-06-29;

Fawzi Nashashibi was interviewed for L'Usine Nouvelle, no 3577, *Automobile le graal de l'autonomie*, 2018-09-20;

Fawzi Nashashibi was interviewed by Laurène Le Fourner for Radio Village Innovation, July 2018.

Fawzi Nashashibi was interviewed for France Info, 2018-09-07.

- For online publications: (Interstices, Images des Maths, Binaire, Wikipedia), and more widely blog articles:

Raoul de Charette was interviewed by K. Haske for MyScienceWork *Where are they now ? Raoul de Charette* [12], 2018-09-04, and by J. Jongwane for Interstices *Les algorithmes de vision pour les véhicules autonomes* [13] [36];

Fawzi Nashashibi was interviewed by Mrs. Barbara Vignaux to prepare an exhibition on the autonomous car for the *Science Actualités* area of the City of Science and Industry (*Cité des Sciences et des Industries*), Paris. It was followed by the development of an article entitled *"Voiture autonome: révolution en route ?"* (Autonomous Car: revolution on the way?);

In January 2018, Gérard Le Lann has been invited to contribute to Blog Binaire Le Monde on: *Sécurité routière et cybersécurité* [14];

In May 18th, an on-line article titled *Inria dévoile son Livre blanc sur les Véhicules Autonomes et Connectés* and relaying the contents of Inria white paper on connected autonomous vehicles was published at http://www.auto-innovations.com/communique/1374.html.

10.3.3. Interventions

- Raoul de Charette and Renaud Poncelet made a demonstration at Inria RII meeting ("Mobilité & environnements", 2018-11-20, Station F, Paris);
- RITS was involved in welcoming schoolchildren in Paris center on December 21st.

11. Bibliography

Major publications by the team in recent years

[1] Z. ALSAYED, G. BRESSON, A. VERROUST-BLONDET, F. NASHASHIBI. *2D SLAM Correction Prediction in Large Scale Urban Environments*, in "ICRA 2018 - International Conference on Robotics and Automation 2018", Brisbane, Australia, May 2018, https://hal.inria.fr/hal-01829091

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[12] https://www.mysciencework.com/omniscience/now-raoul-charette
[13] https://interstices.info/les-algorithmes-de-vision-pour-les-vehicules-autonomes/
[14] http://binaire.blog.lemonde.fr/2018/01/19/securite-routiere-et-cybersecurite/

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[7] Z. ALSAYED. *Characterizing the Robustness and Enhancing the Accuracy of SLAM-based Localization Systems for Autonomous Driving*, Télécom ParisTech, June 2018

[8] C. FLORES. *Control Architecture for Adaptive and Cooperative Car-Following*, PSL Research University, December 2018

[9] F. GARRIDO. *Two-staged local trajectory planning based on optimal pre-planned curves interpolation for human-like driving in urban areas*, PSL Research University, December 2018

[10] F. NAVAS. *Stability analysis for controller switching in autonomous vehicles*, PSL Research University, December 2018

[11] D. V. NGUYEN. *Wireless Sensors Networks for Indoor Mapping and Accurate Localization for Low Speed Navigation in Smart Cities*, PSL Research University, November 2018

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[12] N. BOULILA, M. HADDED, A. LAOUITI, L. AZOUZ SAIDANE. *Hybrid centralised MAC protocol for reliable broadcast of safety messages in vehicular ad hoc network*, in "International Journal of Space-Based and Situated Computing", January 2018, vol. 8, n° 3, pp. 169 - 178 [*DOI :* 10.1504/IJSSC.2018.097294], https://hal.archives-ouvertes.fr/hal-01994662

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