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Institut national des sciences appliquées de Lyon

Activity Report 2019

Project-Team CHROMA

Cooperative and Human-aware Robot Navigation in Dynamic Environments

IN COLLABORATION WITH: Centre of Innovation in Telecommunications and Integration of services

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Robotics and Smart environments

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Creation of the Team: 2015 March 01, updated into Project-Team: 2017 December 01

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2. Overall Objectives

2.1. Origin of the project

Chroma is a bi-localized project-team at Inria Grenoble Rhône-Alpes in Grenoble and Lyon cities. The project was launched at the beginning of the year 2015 (March) before it became an Inria project-team on December 1st, 2017. It brings together experts in perception and decision-making for mobile robotics, all of them sharing common approaches that mainly relate to the field of Artificial Intelligence. It was originally founded by members of Inria project-team eMotion led by Christian Laugier (2002-2014) and teacher-researchers from INSA Lyon [1] working in the robotic group led by Prof. Olivier Simonin in CITI Lab. [2] (since 2013). Earlier members include Olivier Simonin (Prof. INSA Lyon), Christian Laugier (Inria researcher DR1), Jilles Dibangoye (Asso. Prof. INSA Lyon), Agostino Martinelli (Inria researcher CR1). On December 1st, 2015, Anne Spalanzani (Asso. Prof. Univ. Grenoble, HDR) joined the team (she was previously member of eMotion and Prima Inria project-teams).

2.2. Overall Objectives

The overall objective of Chroma is to address fundamental and open issues that lie at the intersection of the emerging research fields called “Human Centered Robotics” [3] and “Multi-Robot Systems (MRS) [4]".

More precisely, our goal is to design algorithms and develop models allowing mobile robots to navigate and cooperate in dynamic and human-populated environments. Chroma is involved in all decision aspects pertaining to single and multi robot navigation tasks, including perception and motion-planning.

The general objective is to build robotic behaviors that allow one or several robots to operate safely among humans in partially known environments, where time, dynamics and interactions play a significant role. Recent advances in embedded computational power, sensor and communication technologies, and miniaturized mechatronic systems, make the required technological breakthroughs possible (including from the scalability point of view).

Chroma is clearly positioned in the "Artificial Intelligence and Autonomous systems" research theme of the **Inria 2018-2022 Strategic Plan**. More specifically we refer to the "Augmented Intelligence" challenge (connected autonomous vehicles) and to the "Human centred digital world" challenge (interactive adaptation).

[1] National Institute of Applied Sciences. INSA Lyon is part of the University de Lyon
[2] Centre of Innovation in Telecommunications and Integration of Service, see http://www.citi-lab.fr/
[3] Montreuil, V.; Clodic, A.; Ransan, M.; Alami, R., "Planning human centered robot activities," in Systems, Man and Cybernetics, 2007. ISIC. IEEE International Conference on , vol., no., pp.2618-2623, 7-10 Oct. 2007
[4] IEEE RAS Multi-Robot Systems http://multirobotsystems.org/

2.3. Research themes

To address the mentionned challenges, we take advantage of recent advances in all: probabilistic methods, planning techniques, multi-agent decision making, and machine learning. We also draw inspiration from other disciplines such as Sociology to take into account human models.

Two main research themes of mobile robotics are addressed : i) Perception and Situation Awareness ii) Navigation and Cooperation in Dynamic Environments. Next, we elaborate more about these themes.

- **Perception and Situation Awareness.** This theme aims at understanding complex dynamic scenes, involving mobile objects and human beings, by exploiting prior knowledge and streams of perceptual data coming from various sensors. To this end, we investigate three complementary research problems:
  - **Bayesian Perception**: How to take into account prior knowledge and uncertain sensory data in a dynamic context?
  - **Situation awareness** : How to interpret the perceived scene and to predict their likely future motion (including near future collision risk) ?
  - **Robust state estimation**: acquire a deep understanding on several sensor fusion problems and investigate their observability properties in the case of unknown inputs.
- **Navigation and Cooperation in Dynamic Environments.** This theme aims at designing models and algorithms allowing robots to move and to coordinate efficiently in dynamic environments. We focus on two problems: navigation in human-populated environment (social navigation) and cooperation in large distributed fleet of robots (scalability and robustness issues).
  - **Motion-planning in human-populated environment.** How to plan trajectories that take into account the uncertainty of human-populated environments and respect the social rules of human beings? Such a challenge requires models of human behavior to be learnt or designed as well as dedicated learning or planning algorithms.
  - **Multi-robot decision making in complex environments.** How to design models and algorithms that can achieve both scalability and performance guarantees in real-world robotic systems? Our methodology builds upon advantages of two complementary approaches, Multi-Agent Sequential Decision Making (MA-SDM) and Swarm Intelligence (SI).

Chroma is also concerned with applications and transfer of the scientific results. Our main applications include autonomous and connected vehicles as well as service robotics. They are presented in Sections 4.2 and 4.3, respectively. Chroma is currently involved in several projects in collaboration with automobile companies (Renault, Toyota and Volvo) and some startups.

3. Research Program

3.1. Introduction

The Chroma team aims to deal with different issues of autonomous mobile robotics : perception, decision-making and cooperation. Figure 1 schemes the different themes and sub-themes investigated by Chroma.

We present here after our approaches to address these different themes of research, and how they combine altogether to contribute to the general problem of robot navigation. Chroma pays particular attention to the problem of autonomous navigation in highly dynamic environments populated by humans and cooperation in multi-robot systems. We share this goal with other major robotic laboratories/teams in the world, such as Autonomous Systems Lab at ETH Zurich, Robotic Embedded Systems Laboratory at USC, KIT [5] (Prof Christoph Stiller lab and Prof Ruediger Dillmann lab), UC Berkeley, Vislab Parma (Prof. Alberto Broggi), and iCeiRA [6] laboratory in Taipei, to cite a few. Chroma collaborates at various levels (visits, postdocs, research projects, common publications, etc.) with most of these laboratories, see Section 9.3.

[5] Karlsruhe Institut fur Technologie
[6] International Center of Excellence in Intelligent Robotics and Automation Research.

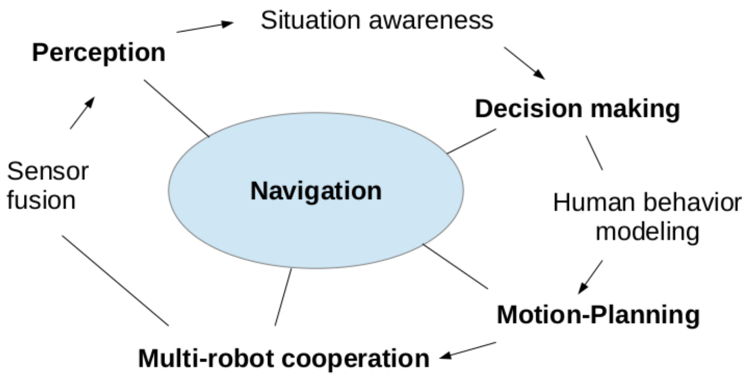

Figure 1. Research themes of the team and their relation

3.2. Perception and Situation Awareness

Robust perception in open and dynamic environments populated by human beings is an open and challenging scientific problem. Traditional perception techniques do not provide an adequate solution for these problems, mainly because such environments are uncontrolled [7] and exhibit strong constraints to be satisfied (in particular high dynamicity and uncertainty). This means that **the proposed solutions have to simultaneously take into account characteristics such as real time processing, temporary occultations, dynamic changes or motion predictions**.

3.2.1. Bayesian perception

Context. Perception is known to be one of the main bottlenecks for robot motion autonomy, in particular when navigating in open and dynamic environments is subject to strong real-time and uncertainty constraints. In order to overcome this difficulty, we have proposed in the scope of the former e-Motion team, a new paradigm in robotics called “Bayesian Perception”. The foundation of this approach relies on the concept of “Bayesian Occupancy Filter (BOF)” initially proposed in the Ph.D. thesis of Christophe Coue [65] and further developed in the team [8]. The basic idea is to combine a Bayesian filter with a probabilistic grid representation of both the space and the motions. It allows the filtering and the fusion of heterogeneous and uncertain sensors data, by taking into account the history of the sensors measurements, a probabilistic model of the sensors and of the uncertainty, and a dynamic model of the observed objects motions.

In the scope of the Chroma team and of several academic and industrial projects (in particular the IRT Security for autonomous vehicle and Toyota projects), we went on with the development and the extension under strong embedded implementation constraints, of our Bayesian Perception concept. This work has already led to the development of more powerful models and more efficient implementations, e.g. the *CMCDOT* (Conditional Monte Carlo Dense Occupancy Tracker) framework [89] which is still under development.

This work is currently mainly performed in the scope of the “Security for Autonomous Vehicle (SAV)” project (IRT Nanoelec), and more recently in cooperation with some Industrial Companies (see section New Results for more details on the non confidential industrial cooperation projects).

[7] partially unknown and open

[8] The Bayesian programming formalism developed in e-Motion, pioneered (together with the contemporary work of Thrun, Burgard and Fox [96]) a systematic effort to formalize robotics problems under Probability theory–an approach that is now pervasive in Robotics.

Objectives. We aim at defining a complete framework extending the Bayesian Perception paradigm to the object level. The main objective is to be simultaneously more robust, more efficient for embedded implementations, and more informative for the subsequent scene interpretation step (Figure 2.a illustrates). Another objective is to improve the efficiency of the approach (by exploiting the highly parallel characteristic of our approach), while drastically reducing important factors such as the required memory size, the size of the hardware component, its price and the required energy consumption. This work is absolutely necessary for studying embedded solutions for the future generation of mobile robots and autonomous vehicles. We also aim at developing strong partnerships with non-academic partners in order to adapt and move the technology closer to the market.

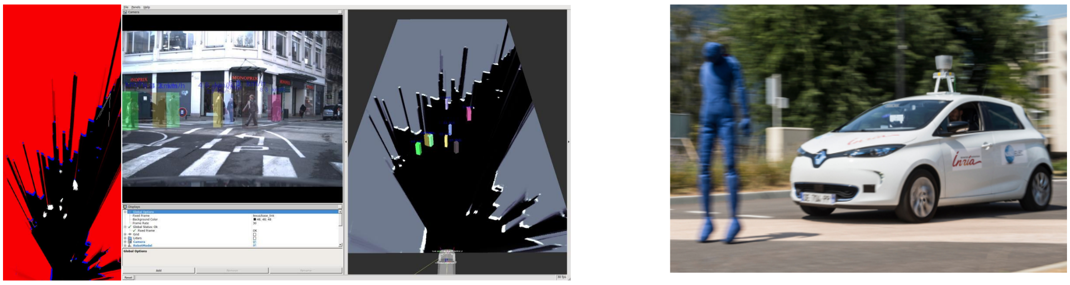

Figure 2. a. Illustration of the Bayesian Perception Paradigm: Filtered occupancy grids, enhanced with motion estimations (vectors) and object detection (colored boxes) b. Autonomous Zoe car of Inria/Chroma.

3.2.2. System validation

Context. Testing and validating Cyber Physical Systems which are designed for operating in various real world conditions, is both an open scientific question and a necessity for a future deployment of such systems. In particular, this is the case for Embedded Perception and Decision-making Systems which are designed for future ADAS [9] and Autonomous Vehicles. Indeed, it is unrealistic to try to be exhaustive by making a huge number of experiments in various real situations. Moreover, such experiments might be dangerous, highly time consuming, and expensive. This is why we have decided to develop appropriate *realistic simulation and statistical analysis tools* for being able to perform a huge number of tests based on some previously recorded real data and on random changes of some selected parameters (the “co-simulation” concept). Such an approach might also be used in a training step of a machine learning process. This is why simulation-based validation is getting more and more popular in automotive industry and research.

This work is performed in the scope of both the SAV [10] project (IRT Nanoelec) and of the EU Enable-S3 project; it is also performed in cooperation with the Inria team Tamis in Rennes, with the objective to integrate the Tamis “Statistical Model Checking” (SMC) approach into our validation process. We are also starting to work on this topic with the Inria team Convecs, with the objective to also integrate formal methods into our validation process.

Objectives. We started to work on this new research topic in 2017. The first objective is to build a “simulated navigation framework” for: (1) constructing realistic testing environments (including the possibility of using real experiments records), (2) developing for each vehicle a simulation model including various physical and dynamic characteristics (e.g. physics, sensors and motion control), and (3) evaluating the performances of a simulation run using appropriate statistical software tools.

[9] Advance Driving Assistance System
[10] Security for Autonomous Vehicles

The second objective is to develop models and tools for automating the Simulation & Validation process, by using a selection of relevant randomized parameters for generating large database of tests and statistical results. Then, a metric based on the use of some carefully selected "Key Performance Indicator" (KPI) has to be defined for performing a statistical evaluation of the results (e.g. by using the above-mentioned SMC approach).

3.2.3. Situation Awareness and Prediction

Context. Predicting the evolution of the perceived moving agents in a dynamic and uncertain environment is mandatory for being able to safely navigate in such an environment. We have recently shown that an interesting property of the Bayesian Perception approach is to generate short-term conservative [11] predictions on the likely future evolution of the observed scene, even if the sensing information is temporary incomplete or not available [84]. But in human populated environments, estimating more abstract properties (e.g. object classes, affordances, agent's intentions) is also crucial to understand the future evolution of the scene. This work is carried out in the scope of the Security of Autonomous Vehicle (SAV) project (IRT Nanoelec) and of several cooperative and PhD projects with Toyota and with Renault.

Objectives. The first objective is to develop an integrated approach for "Situation Awareness & Risk Assessment" in complex dynamic scenes involving multiples moving agents (e.g vehicles, cyclists, pedestrians ...), whose behaviors are most of the time unknown but predictable. Our approach relies on combining machine learning to build a model of the agent behaviors and generic motion prediction techniques (e.g. Kalman-based, GHMM , or Gaussian Processes). In the perspective of a long-term prediction we will consider the semantic level [12] combined with planning techniques.

The second objective is to build a general framework for perception and decision-making in multi-robot/vehicle environments. The navigation will be performed under both dynamic and uncertainty constraints, with contextual information and a continuous analysis of the evolution of the probabilistic collision risk. Interesting published and patented results [76] have already been obtained in cooperation with Renault and UC Berkeley, by using the "Intention / Expectation" paradigm and Dynamic Bayesian Networks. We are currently working on the generalization of this approach, in order to take into account the dynamics of the vehicles and multiple traffic participants. The objective is to design a new framework, allowing us to overcome the short-comings of rules-based reasoning approaches which often show good results in low complexity situations, but which lead to a lack of scalability and of long terms predictions capabilities.

3.2.4. Robust state estimation (Sensor fusion)

Context. In order to safely and autonomously navigate in an unknown environment, a mobile robot is required to estimate in real time several physical quantities (e.g., position, orientation, speed). These physical quantities are often included in a common state vector and their simultaneous estimation is usually achieved by fusing the information coming from several sensors (e.g., camera, laser range finder, inertial sensors). The problem of fusing the information coming from different sensors is known as the *Sensor Fusion* problem and it is a fundamental problem which plays a major role in robotics.

Objective. A fundamental issue to be investigated in any sensor fusion problem is to understand whether the state is observable or not. Roughly speaking, we need to understand if the information contained in the measurements provided by all the sensors allows us to carry out the estimation of the state. If the state is not observable, we need to detect a new observable state. This is a fundamental step in order to properly define the state to be estimated. To achieve this goal, we apply standard analytic tools developed in control theory together with some new theoretical concepts we introduced in [78] (concept of continuous symmetry). Additionally, we want to account the presence of disturbances in the observability analysis.

Our approach is to introduce general analytic tools able to derive the observability properties in the nonlinear case when some of the system inputs are unknown (and act as disturbances). We recently obtained a simple analytic tool able to account the presence of unknown inputs [80], which extends a heuristic solution derived by the team of Prof. Antonio Bicchi [60] with whom we collaborate (Centro Piaggio at the University of Pisa).

[11] i.e. when motion parameters are supposed to be stable during a small amount of time
[12] knowledge about agent's activities and tasks

Fusing visual and inertial data. A special attention is devoted to the fusion of inertial and monocular vision sensors (which have strong application for instance in UAV navigation). The problem of fusing visual and inertial data has been extensively investigated in the past. However, most of the proposed methods require a state initialization. Because of the system nonlinearities, lack of precise initialization can irreparably damage the entire estimation process. In literature, this initialization is often guessed or assumed to be known [70]. Recently, this sensor fusion problem has been successfully addressed by enforcing observability constraints [74] and by using optimization-based approaches [77]. These optimization methods outperform filter-based algorithms in terms of accuracy due to their capability of relinearizing past states. On the other hand, the optimization process can be affected by the presence of local minima. We are therefore interested in a deterministic solution that analytically expresses the state in terms of the measurements provided by the sensors during a short time-interval.

For some years we explore deterministic solutions as presented in [79] and [81]. Our objective is to improve the approach by taking into account the biases that affect low-cost inertial sensors (both gyroscopes and accelerometers) and to exploit the power of this solution for real applications. This work is currently supported by the ANR project VIMAD [13] and experimented with a quadrotor UAV. We have a collaboration with Prof. Stergios Roumeliotis (the leader of the MARS lab at the University of Minnesota) and with Prof. Anastasios Mourikis from the University of California Riverside. Regarding the usage of our solution for real applications we have a collaboration with Prof. Davide Scaramuzza (the leader of the Robotics and Perception group at the University of Zurich) and with Prof. Roland Siegwart from the ETHZ.

3.3. Navigation and cooperation in dynamic environments

In his reference book *Planning algorithms* [14] S. LaValle discusses the different dimensions that made the motion-planning problem complex, which are the number of robots, the obstacle region, the uncertainty of perception and action, and the allowable velocities. In particular, it is emphasized that complete algorithms require at least exponential time to deal with multiple robot planning in complex environments, preventing them to be scalable in practice. Moreover, dynamic and uncertain environments, as human-populated ones, expand this complexity.

In this context, we aim at **scale up decision-making in human-populated environments and in multi-robot systems, while dealing with the intrinsic limits of the robots (computation capacity, limited communication)**.

3.3.1. Motion-planning in human-populated environment

Context. Motion planning in dynamic and human-populated environments is a current challenge of robotics. Many research teams work on this topic. We can cite the Institut of robotic in Barcelone [69], the MIT [57], the Autonomous Intelligent Systems lab in Freiburg [61], or the LAAS [85]. In Chroma, we explore different issues : **integrating the risk (uncertainty) in planning processes, modeling and taking into account human behaviors and flows.**

Objective We aim to give the robot some socially compliant behaviors by anticipating the near future (trajectories of mobile obstacle in the robot's surroundings) and by integrating knowledge from psychology, sociology and urban planning. In this context, we will focus on the following 3 topics.

Risk-based planning. Unlike static or controlled environments [15] where global path planning approaches are suitable, dealing with highly dynamic and uncertain environments requires to integrate the notion of risk (risk of collision, risk of disturbance). Then, we examine how motion planning approaches can integrate this risk in the generation and selection of the paths. An algorithm called RiskRRT was proposed in the previous eMotion team. This algorithm plans goal oriented trajectories that minimize the risk estimated at each instant. It fits environments that are highly dynamic and adapts to a representation of uncertainty [93] (see Figure 3.a for illustration). Now, we extend this principle to be adapted to various risk evaluation methods (proposed in 3.2) and various situation (highways, urban environments, even in dense traffic).

[13] Navigation autonome des drones aériens avec la fusion des données visuelles et inertielles, lead by A. Martinelli, Chroma.
[14] Steven M. LaValle, Planning Algorithms, Cambridge University Press, 2006.
[15] known environment without uncertainty

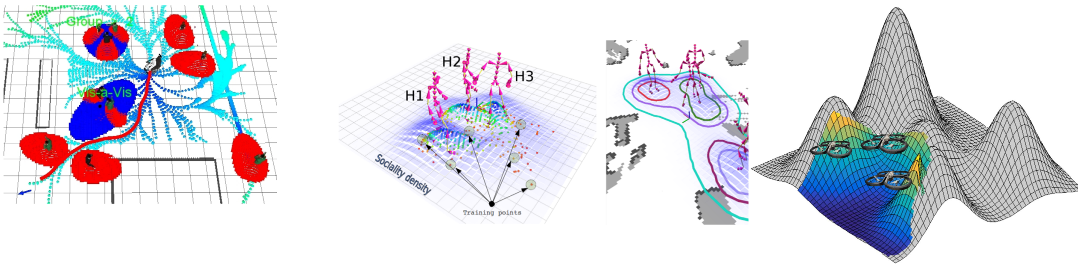

Figure 3. Illustrations of a. the Risk-RRT planning b. The human interaction space model c. Multi-UAV 3D coverage and exploration.

Recently we investigated the automatic learning of robot navigation in complex environments based on specific tasks and from visual input. We address this problem by combining computer vision, machine learning (deep-learning), and robotics path planning (see 7.5.1).

Sharing the physical space with humans. Robots are expected to share their physical space with humans. Hence, robots need to take into account the presence of humans and to behave in a socially acceptable way. Their trajectories must be safe but also predictable, that is why they must follow social conventions, respecting proximity constraints, avoiding people interacting or joining a group engaged in conversation without disturbing. For this purpose, we proposed earlier to integrate some knowledge from the psychology domain (i.e. proxemics theory), see figure 3.b. We aim now to integrate semantic knowledge [16] and psycho-social theories of human behavior [17] [18] in the navigation framework we have developed for a few years (i.e. the Risk-based navigation algorithms [71], [93], [100]). These concepts were tested on our automated wheelchair (see figure 3.c) but they have and will be adapted to autonomous cars, telepresence robots and companion robots. This work is currently supported by the ANR Valet and the ANR Hianic.

3.3.2. Decision Making in Multi-robot systems

Context. A central challenge in Chroma is to define **decision-making algorithms that scale up to large multi-robot systems**. This work takes place in the general framework of Multi-Agent Systems (MAS). The objective is to compute/define agent behaviors that provide cooperation and adaptation abilities. Solutions must also take into account the agent/robot computational limits.

We can abstract the challenge in three objectives :
i) mastering the complexity of large fleet of robots/vehicles (scalability),
ii) dealing with limited computational/memory capacity,
iii) building adaptive solutions (robustness).

Combining Decision-theoretic models and Swarm intelligence.

[16] B. Kuipers, The Spatial Semantic Hierarchy, Artificial Intelligence, Volume 119, Issues 1–2, May 2000, Pages 191-233

[17] Gibson, J. (1977). The theory of affordances, in Perceiving, Acting, and Knowing. Towards an Ecological Psychology. Number eds Shaw R., Bransford J. Hoboken,NJ: John Wiley & Sons Inc.

[18] Hall, E. (1966). The hidden dimension. Doubleday Anchor Books.

Over the past few years, our attempts to address multi-robot decision-making are mainly due to Multi-Agent Sequential Decision Making (MA-SDM) and Swarm Intelligence (SI). MA-SDM builds upon well-known decision-theoretic models (e.g., Markov decision processes and games) and related algorithms, that come with strong theoretical guarantees. In contrast, the expressiveness of MA-SDM models has limited scalability in face of realistic multi-robot systems [19], resulting in computational overload. On their side, SI methods, which rely on local rules – generally bio-inspired – and relating to Self-Organized Systems [20], can scale up to multiple robots and provide robustness to disturbances, but with poor theoretical guarantees [21]. Swarm models can also answer to the need of designing tractable solutions [92], but they remain not geared to express complex realistic tasks or to handle (point-to-point) communication between robots. This motivates our work to go beyond these two approaches and to combine them.

First, we plan to investigate **incremental expansion mechanisms in anytime decision-theoretic planning**, starting from local rules (from SI) to complex strategies with performance guarantees (from MA-SDM) [67]. This methodology is grounded into our research on anytime algorithms, that are guaranteed to stop at anytime while still providing a reliable solution to the original problem. It further relies on decision theoretical models and tools including: Decentralized and Partially Observable Markov Decision Processes and Games, Dynamic Programming, Distributed Reinforcement Learning and Statistical Machine Learning.

Second, we plan to extend the SI approach by considering **the integration of optimization techniques at the local level**. The purpose is to force the system to explore solutions around the current stabilized state – potentially a local optimum – of the system. We aim at keeping scalability and self-organization properties by not compromising the decentralized nature of such systems. Introducing optimization in this way requires to measure locally the performances, which is generally possible from local perception of robots (or using learning techniques). The main optimization methods we will consider are Local Search (Gradient Descent), Distributed Stochastic Algorithm and Reinforcement Learning. We have shown in [97] the interest of such an approach for driverless vehicle traffic optimization.

Both approaches must lead to **master the complexity** inherent to large and open multi-robot systems. Such systems are prone to combinatorial problems, in term of state space and communication, when the number of robots grows. To cope with this complexity we explore several approaches :

- Combining MA-SDM, machine learning and OR [22] techniques to deal with global-local optimization in multi-agent/robot systems. In 2016, we started a collaboration with the VOLVO Group, in Lyon, to deal with VRP problems and optimization of goods distribution using a fleet of autonomous vehicles. We also explore such a methodology in the framework of the collaboration with the team of Prof. G. Czibula (Cluj Univiersity, Romania).
- Defining heuristics by decentralizing global exact solutions. For instance we explore online stochastic-optimization planning to deal with multi-robot coverage/exploration of 3D environments, see Fig 3.c and [42].

Beyond this methodological work, we aim to evaluate our models on benchmarks from the literature, by using simulation tools as a complement of robotic experiments. This will lead us to develop simulators, allowing to deploy tens to thousands robots in constrained environments.

Towards adaptive connected robots.

Mobile robots and autonomous vehicles are becoming more connected to one another and to other devices in the environment (concept of cloud of robots [23] and V2V/V2I connectivity in transportation systems). Such robotic systems are open systems as the number of connected entities is varying dynamically. Network of robots brought with them new problems, as the need of (online) adaption to changes in the system and to the variability of the communication.

[19] Martin L. Puterman, Markov Decision Processes; Stuart Russell and Peter Norvig, Artificial Intelligence - A Modern Approach
[20] D. Floreano and C. Mattiussi, Bio-Inspired Artificial Intelligence - Theories, Methods, and Technologies, MIT Press, 2008.
[21] S. A. Brueckner, G. Di Marzo Serugendo, A. Karageorgos, R. Nagpal (2005). Engineering Self-Organising Systems, Methodologies and Applications. LNAI 3464 State-of-the-Art Survey, Springer book.
[22] Operations Research
[23] see for instance the first International Workshop on Cloud and Robotics, 2016.

In Chroma, we address the problem of adaptation by considering machine learning techniques and local mechanisms as discussed above (SI models). More specifically we investigate the problem of maintaining the connectivity between robots which perform dynamic version of tasks such as patrolling, exploration or transportation, i.e. where the setting of the problem is continuously changing and growing (see [86]).

In Lyon, the CITI Laboratory conducts research in many aspects of telecommunication, from signal theory to distributed computation. In this context, Chroma develops cooperations with the Inria team Agora [86] (wireless communication protocols) and with Dynamid team [63] (middlleware and cloud aspects), that we wish to reinforce in the next years.

4. Application Domains

4.1. Introduction

Applications in Chroma are organized in two main domains : **i) Future cars and transportation systems and ii) Services robotics.** These domains correspond to the experimental fields initiated in Grenoble (eMotion team) and in Lyon (CITI lab). However, the scientific objectives described in the previous sections are intended to apply equally to both applicative domains. Even our work on Bayesian Perception is today applied to the intelligent vehicle domain, we aim to generalize to any mobile robots. The same remark applies to the work on multi-agent decision making. We aim to apply algorithms to any fleet of mobile robots (service robots, connected vehicles, UAVs). This is the philosophy of the team since its creation.

Figure 4. Most of the Chroma platforms: the Pepper robot, a fleet of (22) Turtlebot 2, one of the 4 Bebop drones and the equipped Toyota Lexus.

4.2. Future cars and transportation systems

Thanks to the introduction of new sensor and ICT technologies in cars and in mass transportation systems, and also to the pressure of economical and security requirements of our modern society, this application domain is quickly changing. Various technologies are currently developed by both research and industrial laboratories. These technologies are progressively arriving at maturity, as it is witnessed by the results of large scale experiments and challenges such as the Google's car project and several future products announcements made by the car industry. Moreover, the legal issue starts to be addressed in USA (see for instance the recent laws in Nevada and in California authorizing autonomous vehicles on roads) and in several other countries (including France).

In this context, we are interested in the development of ADAS [24] systems aimed at improving comfort and safety of the cars users (e.g., ACC, emergency braking, danger warnings), and of Fully Autonomous Driving functions for controlling the displacements of private or public vehicles in some particular driving situations and/or in some equipped areas (e.g., automated car parks or captive fleets in downtown centers or private sites).

[24] Advanced Driver Assistance Systems

Since about 8 years, we are collaborating with Toyota and with Renault-Nissan on these applications (bilateral contracts, PhD Theses, shared patents), but also recently with Volvo group (PhD thesis started in 2016). We are also strongly involved (since 2012) in the innovation project Perfect then now Security for autonomous vehicle of the IRT [25] Nanoelec (transportation domain). In 2016, we have been awarded a European H2020 ECSEL project [26] involving major European automotive constructors and car suppliers. In this project, Chroma is focusing on the embedded perception component (models and algorithms, including the certification issue), in collaboration with Renault, Valeo and also with the Inria team TAMIS (Rennes). Chroma is also involved in the ANR project "Valet" (2015-2018) coordinated by the Inria team RITS (Rocquencourt), dealing with automatic redistribution of car-sharing vehicles and parking valet; Chroma is involved in the pedestrian-vehicle interaction for a safe navigation.

In this context, Chroma has two experimental vehicles equipped with various sensors (a Toyota Lexus and a Renault Zoe, see. Fig. 4 and Fig. 2.b), which are maintained by Inria-SED [27] and that allow the team to perform experiments in realistic traffic conditions (Urban, road and highway environments). The Zoe car has been automated in December 2016, through our collaboration with the team of P. Martinet (IRCCyN Lab, Nantes), that allow new experiments in the team.

4.3. Services robotics

Service robotics is an application domain quickly emerging, and more and more industrial companies (e.g., IS-Robotics, Samsung, LG) are now commercializing service and intervention robotics products such as vacuum cleaner robots, drones for civil or military applications, entertainment robots ... One of the main challenges is to propose robots which are sufficiently robust and autonomous, easily usable by non-specialists, and marked at a reasonable cost. We are involved in developing observation and surveillance systems, by using ground robots and aerial ones, see Fig. 4. Since 2016, we develop solutions for 3D observation/exploration of complex scenes or environments with a fleet of UAVs (Dynaflock Inria/DGA project, Inria ADT CORDES [28]) or mobile robots (COMODYS FIL project [82]).

A more recent challenge for the coming decade is to develop robotized systems for assisting elderly and/or disabled people. In the continuity of our work in the IPL PAL [29], we aim to propose smart technologies to assist electric wheelchair users in their displacements and also to conttrol autonomous cars in human crowds (see Figure 17 for illustration). This concerns our recent "Hianic" ANR project. Another emerging application is humanoid robots helping humans at their home or work. In this context, we address the problem of NAMO (Navigation Among Movable Obstacles) in human populated environments (eg. PhD of B. Renault started on 2018). More generally we address navigation and reconnaissance tasks with Pepper humanoids in the context of the RoboCup-Social League.

5. Highlights of the Year

5.1. Highlights of the Year

- Success for European H2020 ICT Robotics project application 'BugWright2' (9M€), led by C. Pradalier (CNRS, GeorgiaTech Metz). O. Simonin leads the multi-robot systems Work-Package (funding for Chroma & Agora teams 600K€). Domain : Autonomous Robotic Inspection and Maintenance on Ship Hulls and Storage Tanks.
- Success for several ANR project applications in the field of Artificial Intelligence :
  - ANR JCJC 'PLASMA' led by J. Dibangoye (250K€)

[25] Institut de Recherche Technologique
[26] ENABLE-S3: European Initiative to Enable Validation for Highly Automated Safe and Secure Systems.
[27] Service Expérimentation et Développement
[28] Coordination d'une Flotte de Drones Connectés pour la Cartographie 3D d'édifices, led by O. Simonin.
[29] Personnaly assisted Living

  - ANR 'DELICIO' led by C. Wolf (510 K€), Chroma is partner.
  - AI Chair led by C. Wolf (520 K€), Chroma is partner (O. Simonin, J. Dibangoye).
- Success for several project applications in the field of Autonomous Vehicles : 2 multi-annual R&D projects with Toyota Motor Europe, a PSPC project ES3CAP leaded by Kalray (3 years), and an EU ECSEL project CPS4EU (3 years).
- Our team LyonTech obtained the 3rd place at the Robocup@Home Pepper league in the 2019 RoboCup competition organized in Sydney (July).
- O. Simonin co-chaired with F. Charpillet (Inria Nancy) the JNRR'2019 bi-annual conference, gathering the French Robotic community (GDR Robotique) ($\sim$ 200 pers.).
- New book by A. Martinelli : "Observability: A new theory based on the group of invariance". To be edited by SIAM on year 2020.
- Exploitation Licenses of CMCDOT have respectively been sold to Toyota and to a French company in the field autonomous vehicles (confidential), with an engineer support for the related transfer of technology.

5.1.1. Awards

BEST PAPER AWARD:

[43]
J. SARAYDARYAN, R. LEBER, F. JUMEL. *People management framework using a 2D camera for human-robot social interactions*, in "RoboCup 2019 - 23rd Annual RoboCup International Symposium", Sydney, Australia, Robocup 2019: Robot World Cup XXIII, July 2019, pp. 1-13, https://hal.archives-ouvertes.fr/hal-02318916

6. New Software and Platforms

6.1. Ground Elevation and Occupancy Grid Estimator (GEOG - Estimator)

KEYWORDS: Robotics - Environment perception

FUNCTIONAL DESCRIPTION: GEOG-Estimator is a system of joint estimation of the shape of the ground, in the form of a Bayesian network of constrained elevation nodes, and the ground-obstacle classification of a pointcloud. Starting from an unclassified 3D pointcloud, it consists of a set of expectation-maximization methods computed in parallel on the network of elevation nodes, integrating the constraints of spatial continuity as well as the influence of 3D points, classified as ground-based or obstacles. Once the ground model is generated, the system can then construct a occupation grid, taking into account the classification of 3D points, and the actual height of these impacts. Mainly used with lidars (Velodyne64, Quanergy M8, IBEO Lux), the approach can be generalized to any type of sensor providing 3D pointclouds. On the other hand, in the case of lidars, free space information between the source and the 3D point can be integrated into the construction of the grid, as well as the height at which the laser passes through the area (taking into account the height of the laser in the sensor model). The areas of application of the system spread across all areas of mobile robotics, it is particularly suitable for unknown environments. GEOG-Estimator was originally developed to allow optimal integration of 3D sensors in systems using 2D occupancy grids, taking into account the orientation of sensors, and indefinite forms of grounds. The ground model generated can be used directly, whether for mapping or as a pre-calculation step for methods of obstacle recognition or classification. Designed to be effective (real-time) in the context of embedded applications, the entire system is implemented on Nvidia graphics card (in Cuda), and optimized for Tegra X2 embedded boards. To ease interconnections with the sensor outputs and other perception modules, the system is implemented using ROS (Robot Operating System), a set of opensource tools for robotics.

- Authors: Amaury Nègre, Lukas Rummelhard, Lukas Rummelhard, Jean-Alix David and Christian Laugier
- Contact: Christian Laugier

6.2. CMCDOT

KEYWORDS: Robotics - Environment perception

FUNCTIONAL DESCRIPTION: CMCDOT is a Bayesian filtering system for dynamic occupation grids, allowing parallel estimation of occupation probabilities for each cell of a grid, inference of velocities, prediction of the risk of collision and association of cells belonging to the same dynamic object. Last generation of a suite of Bayesian filtering methods developed in the Inria eMotion team, then in the Inria Chroma team (BOF, HSBOF, ...), it integrates the managment of hybrid sampling methods (classical occupancy grids for static parts, particle sets for parts dynamics) into a Bayesian unified programming formalism , while incorporating elements resembling the Dempster-Shafer theory (state "unknown", allowing a focus of computing resources). It also offers a projection system of the estimated scene in the near future, to reference potential collisions with the ego-vehicle or any other element of the environment, as well as very low cost pre-segmentation of coherent dynamic spaces (taking into account speeds). It takes as input instantaneous occupation grids generated by sensor models for different sources, the system is composed of a ROS package, to manage the connectivity of I / O, which encapsulates the core of the embedded and optimized application on GPU Nvidia (Cuda), allowing real-time analysis of the direct environment on embedded boards (Tegra X1, X2). ROS (Robot Operating System) is a set of open source tools to develop software for robotics. Developed in an automotive setting, these techniques can be exploited in all areas of mobile robotics, and are particularly suited to highly dynamic and uncertain environment management (eg urban scenario, with pedestrians, cyclists, cars, buses, etc.).

- Authors: Amaury Nègre, Lukas Rummelhard, Jean-Alix David and Christian Laugier
- Partners: CEA - CNRS
- Contact: Christian Laugier

6.3. cuda_grid_fusion

KEYWORDS: Robotics - Environment perception

FUNCTIONAL DESCRIPTION: This module, directly implemented in ROS / Cuda, performs the merge of occupancy grids, defined in the format proposed in CMCDOT (probabilities integrating the "visibility" information of the cell, via the coefficients "unknown") thanks to an original method, allowing not only consistency with the rest of the system, but also a nuanced consideration of confidence criteria towards the various sources of information.

- Authors: Lukas Rummelhard and Jean-Alix David
- Contact: Lukas Rummelhard

6.4. cuda_laser_grid

KEYWORDS: Robotics - Environment perception

FUNCTIONAL DESCRIPTION: This module generates occupation grids from "almost" planar lidar. The sensor model, as well as the outputs, have been modified, in order to be fully consistent with the CMCDOT and grid fusion module formats.

- Authors: Amaury Nègre, Lukas Rummelhard and Jean-Alix David
- Contact: Lukas Rummelhard

6.5. Zoe Simulation

Simulation of Inria's Renault Zoe in Gazebo environment

KEYWORD: Simulation

FUNCTIONAL DESCRIPTION: This simulation represents the Renault Zoe vehicle considering the realistic physical phenomena (friction, sliding, inertia, ...). The simulated vehicle embeds sensors similar to the ones of the actual vehicle. They provide measurement data under the same format. Moreover the software input/output are identical to the vehicle's. Therefoe any program executed on the vehicle can be used with the simulation and reciprocally.

- Authors: Christian Laugier, Nicolas Turro and Thomas Genevois
- Contact: Christian Laugier

6.6. EKF Odom

EKF based localisation for vehicles

KEYWORDS: Localization - Autonomous Cars

FUNCTIONAL DESCRIPTION: This software fuses IMU data with wheel rotation or speed measurement inside an Extended Kalman Filter. It estimates the state position, orientation, speed, angular speed, acceleration.

- Authors: Thomas Genevois and Christian Laugier
- Contact: Christian Laugier
- URL: https://team.inria.fr/chroma/en/

6.7. Light Vehicle Simulation

Simulation of a light vehicle in Gazebo environment

KEYWORD: Simulation

FUNCTIONAL DESCRIPTION: This simulation represents a light vehicle considering the realistic physical phenomena (friction, sliding, inertia, ...). The simulated vehicle embeds sensors similar to the ones of the actual vehicle. They provide measurement data under the same format. Moreover the software input/output are identical to the vehicle's. Therefore any program executed on the vehicle can be used with the simulation and reciprocally.

- Authors: Thomas Genevois and Christian Laugier
- Contact: Christian Laugier
- URL: https://team.inria.fr/chroma/en/

6.8. CarHybridSim

Hybrid simulation for autonomous cars with high traffic

KEYWORDS: Simulation - Autonomous Cars

FUNCTIONAL DESCRIPTION: Open source tool for simulating autonomous vehicles in complex, high traffic, scenarios. The hybrid simulation fully integrates and synchronizes a microscopic, multi-modal traffic simulator and a complex 3D simulator.

- Contact: Mario Garzon Oviedo
- URL: https://github.com/marioney/hybrid_simulation

6.9. SimuDronesGR

Simultion of UAV fleets with Gazebo/ROS

KEYWORDS: Robotics - Simulation

FUNCTIONAL DESCRIPTION: The simulator includes the following functionality : 1) Simulation of the mechanical behavior of an Unmanned Aerial Vehicle : * Modeling of the body's aerodynamics with lift, drag and moment * Modeling of rotors' aerodynamics using the forces and moments' expressions from Philppe Martin's and Erwan Salaün's 2010 IEEE Conference on Robotics and Automation paper "The True Role of Accelerometer Feedback in Quadrotor Control". 2) Gives groundtruth informations : * Positions in East-North-Up reference frame * Linear velocity in East-North-Up and Front-Left-Up reference frames * Linear acceleration in East-North-Up and Front-Left-Up reference frames * Orientation from East-North-Up reference frame to Front-Left-Up reference frame (Quaternions) * Angular velocity of Front-Left-Up reference frame expressed in Front-Left-Up reference frame. 3) Simulation of the following sensors : * Inertial Measurement Unit with 9DoF (Accelerometer + Gyroscope + Orientation) * Barometer using an ISA model for the troposphere (valid up to 11km above Mean Sea Level) * Magnetometer with the earth magnetic field declination * GPS Antenna with a geodesic map projection.

RELEASE FUNCTIONAL DESCRIPTION: Initial version

- Author: Vincent Le Doze
- Partner: Insa de Lyon
- Contact: Vincent Le Doze

6.10. cuda_US_grid

KEYWORDS: Robotics - Environment perception

FUNCTIONAL DESCRIPTION: This module generates occupation grids from data generated by an ultrasonic range sensor. The sensor model, as well as the outputs, have been modified, in order to be fully consistent with the CMCDOT and grid fusion module formats.

- Authors: Christian Laugier and Thomas Genevois
- Partner: CEA
- Contact: Christian Laugier

6.11. Embedded Perception

FUNCTIONAL DESCRIPTION: The method for computing occupancy grids from a stereoscopic sensor, developped in the e-motion team, has been implemented on GPU, using NVIDIA CUDA. This allows a real time implementation and an online processing within the Lexus experimental platform.

- Participants: Amaury Nègre, Christian Laugier and Mathias Perrollaz
- Contact: Christian Laugier

6.12. spank

Swarm Protocol And Navigation Kontrol

KEYWORD: Protocoles

FUNCTIONAL DESCRIPTION: Communication and distance measurement in an uav swarm

- Contact: Stéphane d'Alu
- URL: https://gitlab.inria.fr/dalu/spank

6.13. S-NAMO-SIM

S-NAMO Simulator

KEYWORDS: Simulation - Navigation - Robotics - Planning

FUNCTIONAL DESCRIPTION: 2D Simulator of NAMO algorithms (Navigation Among Movable Obstacles) ROS compatible

RELEASE FUNCTIONAL DESCRIPTION: Creation

- Contact: Benoit Renault

7. New Results

7.1. Robust state estimation (Sensor fusion)

This research is the follow up of Agostino Martinelli's investigations carried out during the last five years, which are in the framework of the visual and inertial sensor fusion problem and the unknown input observability problem.

7.1.1. Visual-inertial structure from motion

Participant: Agostino Martinelli.

We have continued our study on the visual inertial sensor fusion problem in the cooperative case, with a special focus on the case of two agents. During this year, we have carried out an exhaustive analysis of all the singularities and minimal cases of this cooperative sensor fusion problem. As in the case of a single agent and in the case of other computer vision problems, the key of the analysis is the establishment of an equivalence between the cooperative visual-inertial sensor fusion problem and a Polynomial Equation System (PES). In the case of a single agent, the PES consists of linear equations and a single polynomial of second degree. In the case of two agents, the number of second degree equations becomes three and, also in this case, a complete analytic solution can be obtained [19], [20]. The power of the analytic solution is twofold. From one side, it allows us to determine the state without the need of an initialization. From another side, it provides fundamental insights into all the structural properties of the problem. The research of this year has focused on this latter issue. Specifically, we have obtained all the minimal cases and singularities depending on the number of camera images and the relative trajectory between the agents. The problem, when non singular, can have up to eight distinct solutions. The usefulness of this analysis has also been illustrated with simulations. In particular, we have quantitatively obtained how the performance of the state estimation worsens near a singularity. The results of this research will be published by the Robotics and Automation Letter (RA-L) journal [18].

7.1.2. Unknown Input Observability

Participant: Agostino Martinelli.

The Unknown Input Observability problem (UIO) in the nonlinear case was an open problem since the sixties years, when it was solved only in the linear case. In the last five years, I have obtained its general analytic solution. So far, I only published the solution for systems characterized by driftless dynamics. In particular, this solution was published as a full paper on the IEEE Transaction on Automatic Control [17]. In December 2018, I was invited by the Society for Industrial and Applied Mathematics (SIAM) to write a book with the general solution. This has been the main work of this year. Since this general solution is based on tensorial calculus (Ricci algebra) and many mathematics procedures and tricks borrowed from theoretical physics, the scope of book has gone much more beyond the presentation of the solution. Basically, by writing this book, I've obtained a new theory of observability.

The current theory of nonlinear observability, does not capture/exploit the key features that are intimately related to the concept of observability. This results in two important limitations:

- The theory, although simple and based on elementary mathematics, can be sometimes burdensome with the risk of easily loosing the meaning of the results and losing the meaning of their assumptions.
- More complex observability problems (e.g., the unknown input observability problem to which this book provides the complete analytic solution) remained unsolved for half a century.

The key to overcome the two above limitations, consists in building a new theory of observability that accounts for the **group of invariance that is inherent to the concept of observability**. This is the typical manner the research in physics has always proceeded. To this regard, I wish to emphasize that the derivation of the basic equations of any physics theory (e.g., the General Relativity, the Yang Mills theory, the Quantum Chromodynamics) starts precisely from the characterization of the group of invariance of the theory.

One of the major novelties introduced by this book is the characterization of the group of invariance of observability and, regarding the case of unknown inputs, the characterization of a subgroup that was called the *Simultaneous Unknown Input Output transformations' group*.

In summary, the book provides several novelties with respect to the existing literature in control theory. Specifically, the reader will learn the following:

- The solution of two open problems in control theory (the book provides separately the solution and the derivation), which are:
  - The extension of the observability rank condition to nonlinear systems driven by also unknown inputs.
  - The extension of the observability rank condition to nonlinear, time-variant systems (both in presence and in absence of unknown inputs)
- A new and more palatable derivation of the existing results in nonlinear observability.
- A new manner of approaching scientific and technological problems, borrowed from theoretical physics (a chapter summarizes in a very intuitive and quick manner the basic mathematics, which includes tensorial calculus).
- A new manner of dealing with the variable *time* in system theory, which is obtained by introducing a new framework, which was called the *chronospace*.

I believe this book could be an opportunity for control and information theory communities to borrow basic mathematics, tricks, types of reasoning from theoretical physics to revisit many aspects of control and information theory.

7.2. Bayesian Perception

Participants: Christian Laugier, Lukas Rummelhard, Jean-Alix David, Jerome Lussereau, Thomas Genevois, Nicolas Turro [SED], Rabbia Asghar, Mario Garzon.

Recognized as one of the core technologies developed within the team over the years (see related sections in previous activity report of Chroma, and previously e-Motion reports), the CMCDOT framework is a generic Bayesian Perception framework, designed to estimate a dense representation of dynamic environments and the associated risks of collision, by fusing and filtering multi-sensor data. This whole perception system has been developed, implemented and tested on embedded devices, incorporating over time new key modules. In 2019, this framework, and the corresponding software, has continued to be the core of many important industrial partnerships and academic contributions, and to be the subject of important developments, both in terms of research and engineering. Some of those recent evolutions are detailed below.

In 2019, the new results have been presented in several invited talks given in some of the major international conferences of the domain [30], [28], [26], [29], [27].

7.2.1. Conditional Monte Carlo Dense Occupancy Tracker (CMCDOT) Framework

Participants: Lukas Rummelhard, Jerome Lussereau, Jean-Alix David, Thomas Genevois, Christian Laugier, Nicolas Turro [SED].

Important developments in the CMCDOT (Fig. 5), in terms of calculation methods and fundamental equations, were introduced and tested. These developments are currently being patented, and will then be used for academic publications. These changes lead to a much higher update frequency, greater flexibility in the management of transitions between states (and therefore a better system reactivity), as well as to the management of a high variability in sensor frequencies (for each sensor over time, and in the set of sensors). The changes include:

- Grid fusion: a new fusion of occupancy grids, enhanced with "unknown" variables, has been developed and implemented. The role of unknown variables has also been enlarged. Currently being patented, it should be the subject of an upcoming paper.
- Ground Estimator: a new method of occupancy grid generation, more accurately taking into account the height of each laser beam, has been developed. Currently being patented, it should be the subject of an upcoming paper.
- Software optimization: the whole CMCDOT framework has been developed on GPUs (implementations in C++/Cuda). An important focus of the engineering has always been, and continued to be in 2019, on the optimization of the software and methods to be embedded on low energy consumption embedded boards (Nvidia Jetson TX1, TX2, AGX Xavier).

Figure 5. CMCDOT results

7.2.2. Multimodal Bayesian perception

Participants: Thomas Genevois, Christian Laugier.

The objective is to extend the concept of Bayesian Perception to the fusion of multiple sensing modalities (including raw data provided by low cost sensors). In 2019, we have developed and implemented a Bayesian model dedicated to ultrasonic range sensors. For any given measurement provided by the sensor, the model computes the occupancy probability in a 2 dimensional grid around the sensor. This computation takes into account the accuracy and the possibility to "miss" an object. Thanks to various parameters, this model has been applied to the sensors of our Renault Zoe demonstrator and to the low cost sensors of our light vehicle demonstrator (flycar).

Fig. 6.a shows an example, developed and implemented on our light vehicle demonstrator. In this example, the perception is relying on 1 lidar and 5 ultrasonic range sensors. An occupancy grid is generated for each sensor. Then they are fused in a single occupancy grid which is filtered using the CMCDOT approach.

7.2.3. Embedding deep learning for semantics

Participants: Thomas Genevois, Christian Laugier.

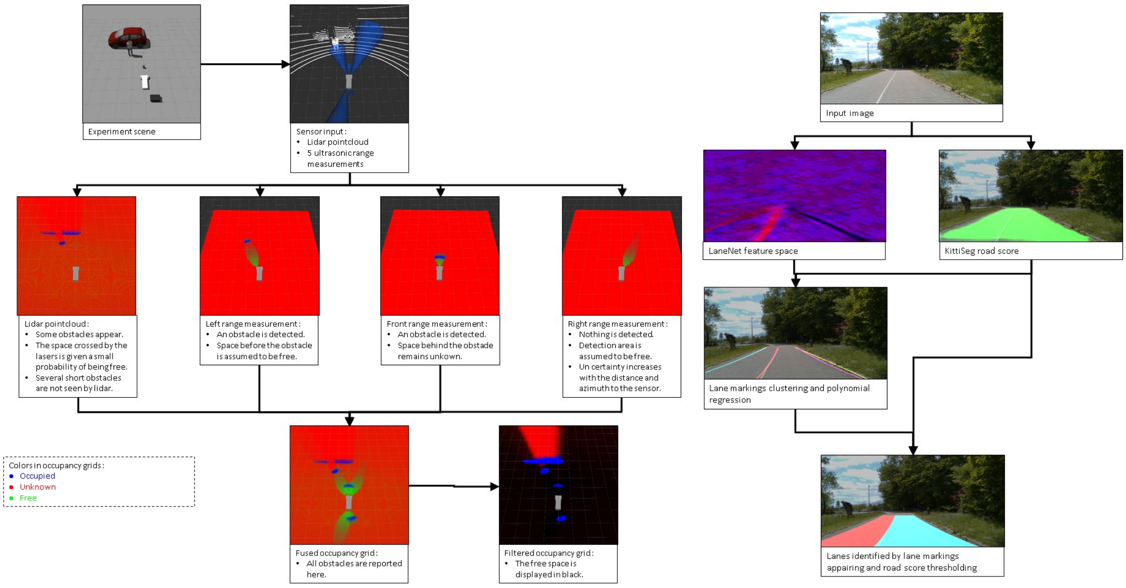

Figure 6. a. Example of multimodal perception, implemented both in simulation and on an actual vehicle demonstrator. b. Combining LaneNet and KittiSeg into a common lane recognition tool.

The objective is to improve embedded Bayesian Perception outputs in our experimental vehicle platforms (Renault Zoe and Flycar), by adding semantics obtained using RGB images and embedded deep learning approaches. In 2019, we have tested several networks for road scene semantic segmentation and implemented two of them in our vehicle platforms:

- LaneNet is a network that provides lane markings detection in road scenarios [83]
- KittiSeg is a network that performs the segmentation of roads [95]

Therefore, Kittiseg is used to identify the shape of the road within an RGB image and LaneNet is used to identify the lane markings that divide the road into lanes. Upon this, we have developed a post-processing technique based on filtering, clustering and regression (Fig. 6.b). This post-processing technique makes the whole system far more robust and allows to express the lanes in a simple way (polynomial curves in the vehicle's base frame).

Since the objective is to embed semantic segmentation tools on our vehicle platforms, an emphasis has been put on the related embedded constraints (in particular strong real time constraints and appropriate light hardware such as the NVIDIA Jetson TX2). However, the networks LaneNet and KittiSeg have not been optimized neither for real-time inference nor for inference on light hardware. This is why we had to propose an approach for adapting these networks to our strong embedded constraints. This approach relies on the following three main steps: Reducing the resolution of the input image, Removing all computations not needed at inference (some parts of the networks are only needed in the learning phase), Adapting the network's shape to the hardware.

These optimization steps have been followed for KittiSeg and LaneNet networks. The improvement is obvious. Namely, for the network LaneNet the initial inference needed 334 operations while, after optimization, it needs only 10 operations. The inference initially runs at 0.3Hz on our board NVIDIA Jetson TX2 while, after optimization, it runs at 10Hz. Also the memory needed for inference is divided by two due to the optimization.

7.2.4. Online map-relative localization

Participants: Rabbia Asghar, Mario Garzon, Jerome Lussereau, Christian Laugier.

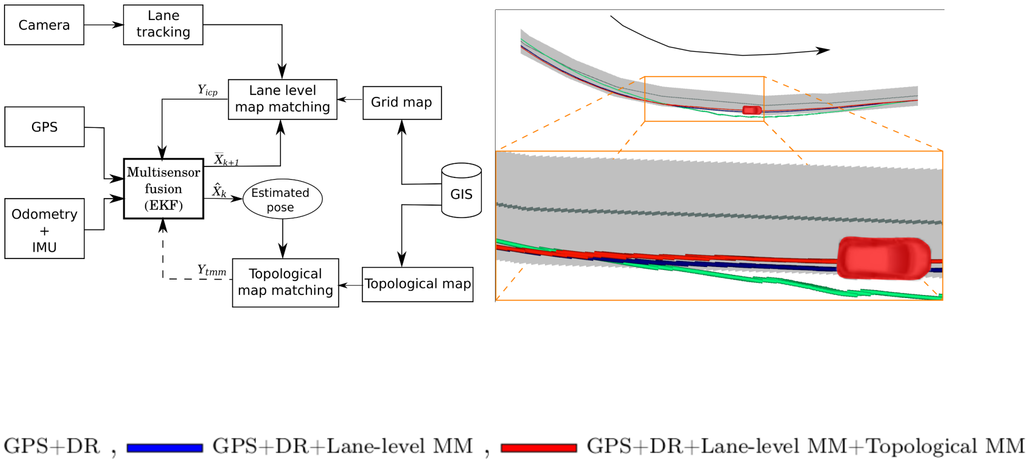

Figure 7. (a) Overview of the map relative localization approach. (b) Estimated pose of the vehicle using three different localization approaches on a curved section of road. The vehicle is provided as a reference where the estimate vehicle pose is just at the curb of the road. Black arrow represents direction of travel.

Localization is one of the key components of the system architecture of autonomous driving and Advanced Driver Assistance Systems (ADAS). Accurate localization is crucial to reliable vehicle navigation and acts as a prerequisite for the planning and control of autonomous vehicles. Offline digital maps are readily available especially in urban scenarios and they play an important role in the field of autonomous vehicles and ADAS. In this framework, we have developed a novel approach for online vehicle localization in a digital map. Two distinct map matching algorithms are proposed:

- Iterative Closest Point (ICP) based lane level map matching (Ll.MM) is performed with visual lane tracker and grid map.
- Decision-rule (DR) based approach is used to perform topological map matching (T. MM).

Results of both map matching algorithms are fused together with GPS and dead reckoning using Extended Kalman Filter to estimate the vehicle's pose relative to the map (see Fig. 7). The approach has been validated on real life conditions on a road-equipped vehicle using a readily available, open source map. Detailed analysis of the experimental results show improved localization using the two aforementioned map matching algorithms (see [50] for more details).
This research work has been carried out in the scope of Project Tornado. A paper on this work was submitted to ICRA2020 and is awaiting review.

7.2.5. System Validation using Simulation and Formal Methods

Participants: Alessandro Renzaglia, Anshul Paigwar, Mathieu Barbier, Philippe Ledent [Chroma/Convecs], Radu Mateescu [Convecs], Christian Laugier, Eduard Baranov [Tamis], Axel Legay [Tamis].

Since 2017, we are working on novel approaches, tools and experimental methodologies with the objective of validating probabilistic perception-based algorithms in the context of autonomous driving. To achieve this goal, a first approach based on Statistical Model Checking (SMC) has been mainly studied in the scope of the European project Enable-S3 and in collaboration with the Inria team Tamis. In this work, we studied the behavior of specifically defined Key Performance Indicators (KPIs), expressed as temporal properties depending on a set of identified metrics, during a large number of simulations via a statistical model checker. As a result, we obtained an evaluation of the probability for the system to meet the KPIs. In particular, we show how this method can be applied to two different subsystems of an autonomous vehicle: a perception system and a decision-making approach for intersection crossing [31]. A more detailed description of the validation scheme for the decision-making approach has been also presented in [49]. This work has been developed in the framework of M. Barbier's PhD thesis, which has been defended in December 2019 [11]. In parallel, in [38], we also proposed a methodology based on a combination of simulation, formal verification, and statistical analysis to validate the collision-risk assessment generated by the Conditional Monte Carlo Dense Occupancy Tracker (CMCDOT), a probabilistic perception system developed in the team. This second work is in collaboration with the Inria team Convecs.

In both cases, the validation methodology relies on the simulation of realistic scenarios generated by using the CARLA simulator [30]. CARLA simulation environment consists of complex urban layouts, buildings and vehicles rendered in high quality, allowing for a realistic representation of real-world scenarios. The ego-vehicle and its sensors, as well as other moving vehicles can be so configured in the simulation to match with the actual system. In order to be able to efficiently generate a large number of execution traces, we have perfected a parameter-based approach which streamlines the process through which the dimensions and initial position and velocity of non-ego vehicles are specified.

We also collected several traces in real experiments by imitating the collision of the ego-vehicle (equipped Renault Zoe) with a pedestrian (by using a mannequin) and with another vehicle (by throwing a big ball). Since it is unfeasible to generate with real experiments a statistically significant number of traces, we focused our analysis on studying how close the simulation traces are to these real experiments by comparing analogous scenarios. These results have been recently submitted to ICRA and are currently under review [31].

7.2.6. Industrial partners and technological transfer

Participants: Christian Laugier, Lukas Rummelhard, Jerome Lussereau, Jean-Alix David, Thomas Genevois.

In 2019, a significant amount of work has been done with the objective to transfer our Bayesian Perception technologies to industrial companies. In a first step, we have developed a new version of CMCDOT based on a clear split of ROS middle-ware code and of GroundEstimator/CMCDOT CUDA code. This allowed us to develop a new version of CMCDOT using the RTMAPS middleware for Toyota Motor Europe. It also allowed us to transfer the CMCDOT technology to some other industrial partners (confidential), in the scope of the project "Security of Autonomous Vehicle" of IRT Nanoelec. Within the IRT Nanoelec framework, we also developed a new "light urban autonomous vehicle" operating using an appropriate version of the CMCDOT and having the capability to navigate with low cost sensors. A first demo of the prototype of this light vehicle has been shown in December 2019, and a start-up project (named Starlink) is currently in incubation.

7.2.7. Autonomous vehicle demonstrations

Participants: Lukas Rummelhard, Jean-Alix David, Thomas Genevois, Jerome Lussereau, Christian Laugier.

In 2019, Chroma has participated to two main public demonstrations:

- **IEEE IV 2019 Conference** (Versailles Satory, June 2019): A one day public demonstration of our Autonomous Vehicle Embedded Perception System has been done using our Renault Zoe platform. Fig. 8.a and 8.b show, respectively, the demonstration track (yellow track) and our booth & demonstration vehicle. During the day, we regularly drove people in our Zoe platform for demonstrating how the perception system was working in various situations.

[30] http://carla.org/

[31] A. Paigwar, E. Baranov, A. Renzaglia, C. Laugier and A. Legay, "Probabilistic Collision Risk Estimation for Autonomous Driving: Validation via Statistical Model Checking", *submitted to* IEEE ICRA20.

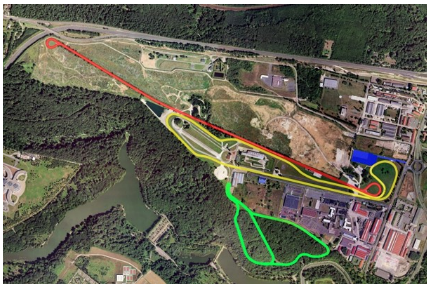

Figure 8. Demonstration at the IV2019 conference : a) track b) demonstration event.

- **FUI Tornado mid-project event** (Rambouillet, September 2019): This one week event included public demonstrations and several open-road tests. During this week, we tested the technologies developed in the scope of the project and we made public and official (for persons from the French Ministries) demonstrations with our Renault Zoe vehicle.

7.3. Situation Awareness & Decision-making for Autonomous Vehicles

Participants: Ozgur Erkent, Christian Wolf, Christian Laugier, Olivier Simonin, Mathieu Barbier, David Sierra-Gonzalez, Jilles Dibangoye, Mario Garzon, Anshul Paigwar, Manuel Alejandro Diaz-Zapata, Victor Romero-Cano [Universidad Autónoma de Occidente, Cali, Colombia], Andrés E. Gómez H., Luiz Serafim-Guardini.

In this section, we include all the novel results in the domains of perception, motion prediction and decision-making for autonomous vehicles. In 2019, these results have also been presented in several invited talks given in some of the major international conferences of the domain [30], [28], [26], [29], [27].

7.3.1. End-to-End Learning of Semantic Grid Estimation Deep Neural Network with Occupancy Grids

Participants: Özgür Erkent, Christian Wolf, Christian Laugier.

Semantic grid is a spatial 2D map of the environment around an autonomous vehicle consisting of cells which represent the semantic information of the corresponding region such as *car, road, vegetation, bikes, etc.*. It consists of an integration of an occupancy grid, which computes the grid states with a Bayesian filter approach, and semantic segmentation information from monocular RGB images, which is obtained with a deep neural network. The network fuses the information and can be trained in an end-to-end manner. The output of the neural network is refined with a conditional random field [15]. The contributions of the study are:

- An end-to-end trainable deep learning method to obtain the semantic grids by integrating the occupancy grids obtained by a Bayesian filter approach and the semantically segmented images by using the monocular RGB images of the environment.
- Grid refinement with conditional random fields (CRFs) on the output of the deep network.
- A comparison of the performances of three different semantic segmentation network architectures in the proposed end-to-end trainable setting.

The proposed method is tested in various datasets (KITTI dataset, Inria-Chroma dataset and SYNTHIA) and different deep neural network architectures are compared (Fig. 9).

7.3.2. Attentional PointNet for 3D object detection in Point Cloud

Participants: Anshul Paigwar, Özgür Erkent, Christian Wolf, Christian Laugier.

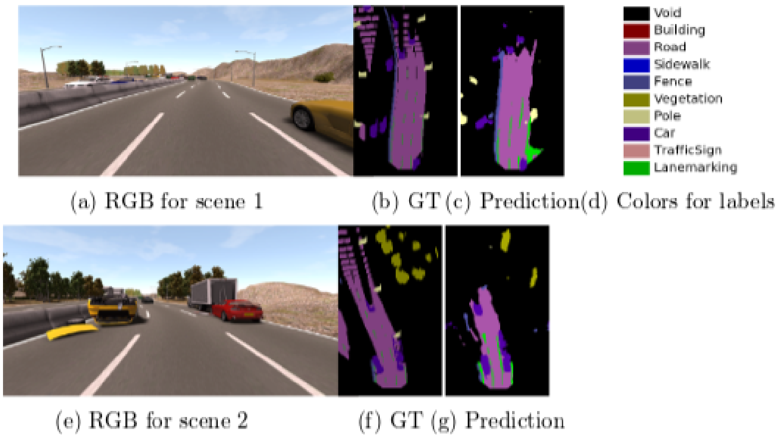

Figure 9. Two scenes with RGB image, ground truth (GT), semantic and segmentation predictions from SYNTHIA dataset.

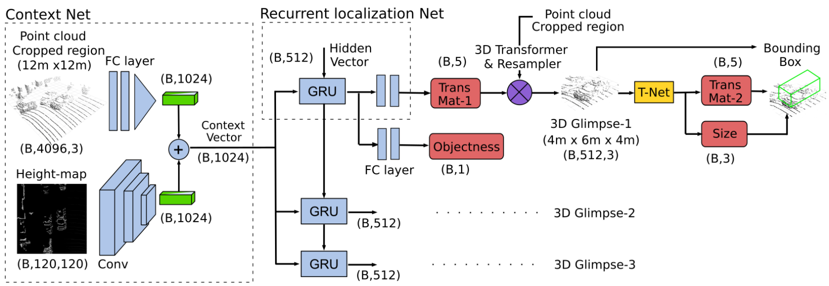

*Figure 10. **Attentional PointNet Architecture**: Given the point cloud and the corresponding height map, network sequentially regress parameters of a 3D Transformation matrix representing pose of a fixed size 3D glimpse. A modified PointNet (T-Net) then estimates another 3D transformation matrix and size representing the 3D bounding box of the object inside the glimpse. Where B is the batch size.*

Accurate detection of objects in 3D point clouds is a central problem for autonomous navigation. Approaches like PointNet [87] that directly operate on sparse point data have shown good accuracy in the classification of single 3D objects. However, LiDAR sensors on Autonomous Vehicles generate a large scale point cloud. Real-time object detection in such a cluttered environment still remains a challenge. In this study, we propose Attentional PointNet, which is a novel end-to-end trainable deep architecture for object detection in point clouds (Fig. 10). We extend the theory of visual attention mechanisms to 3D point clouds and introduce a new recurrent 3D Localization Network module. Rather than processing the whole point cloud, the network learns where to look (finding regions of interest), which significantly reduces the number of points to be processed and inference time. Evaluation on KITTI [72] car detection benchmark shows that our Attentional PointNet achieves comparable results with the *state-of-the-art* LiDAR-based 3D detection methods in detection (Fig. 11) and speed.

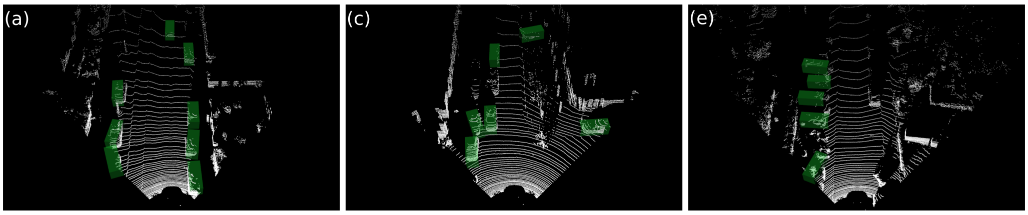

Figure 11. Visualizations of ***Attentional PointNet*** *results on KITTI dataset for the car category shows model's ability to detect multiple objects in cluttered environments*

This work has been published in CVPR 2019 - Workshop for Autonomous Driving, Long Beach, California, USA [39].

7.3.3. Panoptic Segmentation

Participants: Manuel Alejandro Diaz-Zapata, Victor Romero-Cano [Universidad Autónoma de Occidente, Cali, Colombia], Özgür Erkent, Christian Laugier.

This work has been accomplished during the internship of Manuel Alejandro Diaz Zapata at Inria-Rhone Alpes under supervision of Ozgur Erkent, Victor Romero-Cano and Christian Laugier at Chroma Project Team. Manuel Alejandro Diaz Zapata was a student of Mechatronic Engineering at Universidad Autónoma de Occidente, Colombia during his internship [52].

Semantic segmentation labels an image at the pixel level, where amorphous regions of similar texture or material such as grass, sky or road are given a label depending on the class. Instance segmentation focuses on countable objects such as people, cars or animals by delimiting them in the image using bounding boxes or a segmentation mask. To reduce the gap between the methods used to detect uncountable objects, and things or countable objects, panoptic segmentation has been proposed [75].

We propose a model consisting of three modules: the semantic segmentation module, the instance segmentation module and the panoptic head (Fig.12). Here the semantic segmentation is done by the MobileNetV2 [90] and the instance segmentation is done by Mask R-CNN [73]. The outputs of both networks are joint by the Panoptic Head. The results are provided on two different datasets.

7.3.4. Recognition of dynamic objects for risk assessment

Participants: Andrés E. Gómez H., Özgür Erkent, Christian Laugier.

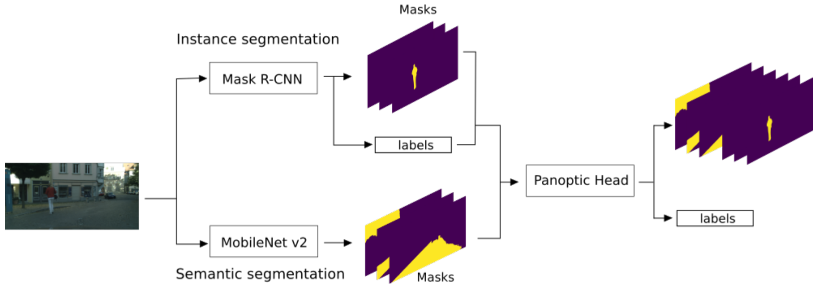

Figure 12. Proposed model for panoptic segmentation.

The Conditional Monte Carlo Dense Occupancy Tracker (*CMCDOT*) framework has proved its accuracy in describing *2D* spatial maps for the Zoe platform. However, this method nowadays cannot recognize the objects in the surrounding. Specifically, the identification of dynamical objects will let us consider different methodologies of risk assessment. This procedure can be possible, through the fusion of RGB and dynamical occupancy grids information.

In the fusion process development, we took into consideration the following steps: *i)* selection of a deep-learning approach, *ii)* development of the projective transformations and *iii)* joining the sub-results. In each step, we used real data from the Zoe platform. In the first step, the *YoloV3* was the deep-learning approach chosen for its accuracy and time performance. In the second step, the projective transformations let us compute the representation of the dynamical points obtained from the occupancy grid plane (i.e., *CMCDOT* framework) in the image plane. Finally, in the third step, we compare the result obtained between the last two-step to identify the dynamic objects around the Zoe platform.

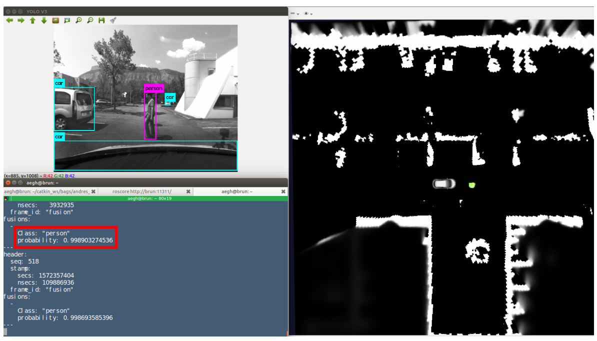

Figure 13. Identification of a pedestrian moving in front of the Zoe platform using the fusion process proposed.

Figure 13 lets us observe the inputs needed for the fusion process and its result.

The work described in this section was done during 2019, inside the activities developed for the Star project. The future work in our project aims to consider the velocity and direction of the dynamic points to define and implement risk behavior functions.

7.3.5. Driving behavior assessment and anomaly detection for intelligent vehicles

Participants: Chule Yang [Nanyang Technological University], Alessandro Renzaglia, Anshul Paigwar, Christian Laugier, Danwei Wang [Nanyang Technological University].

Ensuring safety of both traffic participants and passengers is an important challenge for rapidly growing autonomous vehicle technology. To this purpose, intelligent vehicles not only have to drive safe but must be able to safeguard themselves from other abnormally driving vehicles and avoid potential collisions [56]. Anomaly detection is one of the essential abilities in behavior analysis, which can be used to infer the moving intention of other vehicles and provide evidence for collision risk assessment. In this work, we propose a behavior analysis method based on Hidden Markov Model (HMM) to assess the driving behavior of vehicles on the road and detect anomalous moments. The algorithm uses the real-time velocity and position of the surrounding vehicles provided by the Conditional Monte Carlo Dense Occupancy Tracker (CMCDOT) [89] framework. The movement of each vehicle can be classified into several observation states, namely, Approaching, Braking, Lane Changing, and Lane Keeping. Finally, by chaining these observation states using a Markov model, the abnormality of driving behavior can be inferred into Normal, Attention, and Risk. We perform experiments using CARLA simulator environment to simulate abnormal driving behaviors as shown in Fig. 14, and we provide results showing the successful detection of abnormal situations.

This work has been published in IEEE CIS-RAM 2019, Bangkok [45].

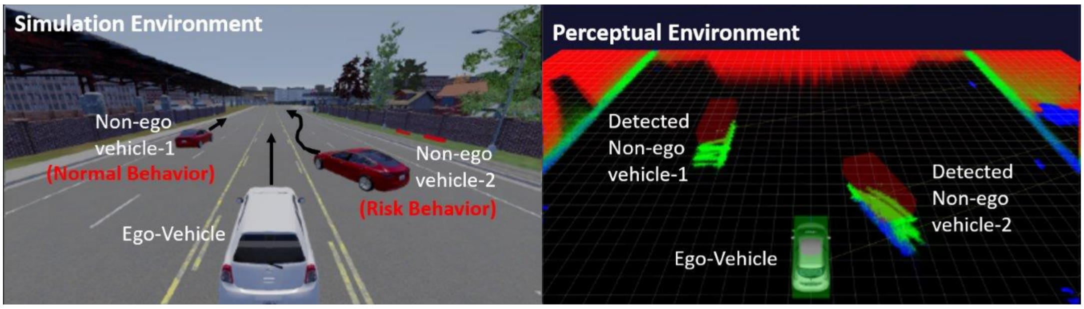

Figure 14. (Left) Simulation environment with CARLA simulator. The white vehicle is the ego-vehicle and two non-ego vehicles are simulated to perform anomaly movements. (Right) Perceptual environment with CMCDOT framework. By analyzing the real-time velocity and position of vehicles, the state and behavior of vehicles can be inferred.

7.3.6. Human-Like Decision-Making for Automated Driving in Highways

Participants: David Sierra-Gonzalez, Mario Garzon, Jilles Dibangoye, Christian Laugier.

Sharing the road with humans constitutes, along with the need for robust perception systems, one of the major challenges holding back the large-scale deployment of automated driving technology. The actions taken by human drivers are determined by a complex set of interdependent factors, which are very hard to model (e.g. intentions, perception, emotions). As a consequence, any prediction of human behavior will always be inherently uncertain, and becomes even more so as the prediction horizon increases. Fully automated vehicles are thus required to make navigation decisions based on the uncertain states and intentions of surrounding vehicles. Building upon previous work, where we showed how to estimate the states and maneuver intentions of surrounding drivers [91], we developed a decision-making system for automated vehicles in highway environments. The task is modeled as a Partially Observable Markov Decision Process and solved in an online fashion using Monte Carlo tree search. At each decision step, a search tree of beliefs is incrementally built and explored in order to find the current best action for the ego-vehicle. The beliefs represent the predicted state of the world as a response to the actions of the ego-vehicle and are updated using an interaction- and intention-aware probabilistic model. To estimate the long-term consequences of any action, we rely on a lightweight model-based prediction of the scene that assumes risk-averse behavior for all agents. We refer to the proposed decision-making approach as human-like, since it mimics the human abilities of anticipating the intentions of surrounding drivers and of considering the long-term consequences of their actions based on an approximate, common-sense, prediction of the scene. We evaluated the proposed approach in two different simulated navigational tasks: lane change planning and longitudinal control. The results obtained demonstrated the ability of the proposed approach to make foresighted decisions and to leverage the uncertain intention estimations of surrounding drivers.

This work was published in ITSC 2019 [44]. It constitutes the last contribution of the PhD dissertation of David Sierra González, which was defended in April 2019 [12].

7.3.7. Contextualized Emergency Trajectory Planning using severity curves

Participants: Luiz Serafim Guardini, Anne Spalanzani, Christian Laugier, Philippe Martinet.

Perception and interpretation of the surroundings is essential for human drivers as well as for (semi-)autonomous vehicles navigation. To improve such interpretation, a lot of effort has been put in place, for example predicting the behavior of pedestrians and other drivers. Nevertheless, to date, cost maps still have considered simple contextualized objects (for instance, binary allowed/forbidden zones or a fixed weight to each type of object). In this work, the risk of injury issued by accidentology is employed to each class of object present in the scene. The scene is analyzed according to dynamic characteristics related to the Ego vehicle and enclosing objects. The aim is to have a better assessment of the surroundings by creating a navigation cost map and to get an improvement on the understanding of the collision severity in the scene. During the first year of his PhD, Luiz Serafim Gaurdini focused on the development of a probabilistic costmap that expresses the Probability of Collision with Injury Risk (PCIR) (see an example on Figure 15). On top of the information gathered by sensors, it includes the severity of injury in the event of a collision between ego and the objects in the scene. This cost map provides enhanced information to perform vehicle motion planning.

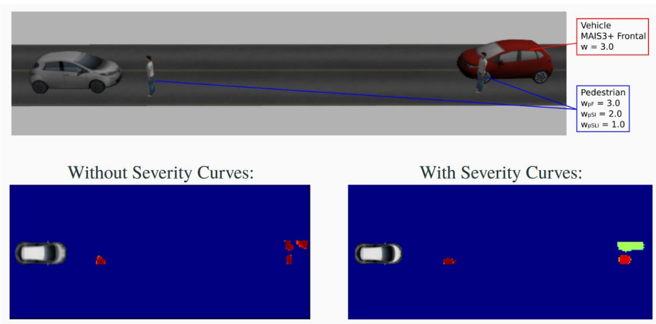

Figure 15. Illustration of the Probabilistic Costmap including the notion of Injury Risk

7.3.8. Game theoretic decision making for autonomous vehicles' merge manoeuvre in high traffic scenarios

Participants: Mario Garzon, Anne Spalanzani.

The goal of this work is to provide a solution for a very challenging task: the merge manoeuvre in high traffic scenarios (see Figure 16). Unlike previous approaches, the proposed solution does not rely on vehicle-to-vehicle communication or any specific coordination, moreover, it is capable of anticipating both the actions of other players and their reactions to the autonomous vehicle's movements. The game used is an iterative, multi-player level-k model,which uses cognitive hierarchy reasoning for decision making and has been proved to correctly model human decisions in uncertain situations. This model uses reinforcement learning to obtain a near-optimal policy, and since it is an iterative model, it is possible to define a goal state so that the policy tries to reach it. To test the decision making process, a kinematic simulation was implemented. The resulting policy was compared with a rule-based approach. The experiments show that the decision making system is capable of correctly performing the merge manoeuvre, by taking actions that require reactions of the other players to be successfully completed. This work was published in [48].

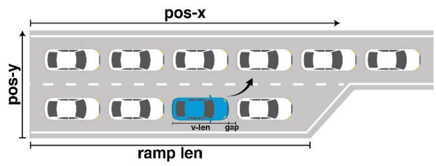

Figure 16. Typical scenario of changing lane in high traffic

7.4. Motion-planning in dense pedestrian environments

We study new motion planning algorithms to allow robots/vehicles to navigate in human populated environment, and to predict human motions. Since 2016, we investigate several directions exploiting vision sensors : prediction of pedestrian behaviors in urban environments (extended GHMM), mapping of human flows (statistical learning), and learning task-based motion planning (RL+Deep-Learning). The works of year 2019 are presented below.

7.4.1. Urban Behavioral Modeling

Participants: Pavan Vasishta, Anne Spalanzani, Dominique Vaufreydaz.

The objective of modeling urban behavior is to predict the trajectories of pedestrians in towns and around cars or platoons (PhD work of P. Vasishta). We first proposed to model pedestrian behaviour in urban scenes by combining the principles of urban planning and the sociological concept of Natural Vision. This model assumes that the environment perceived by pedestrians is composed of multiple potential fields that influence their behaviour. These fields are derived from static scene elements like side-walks, cross-walks, buildings, shops entrances and dynamic obstacles like cars and buses for instance. This work was published in [98]. We then developed an extension to the Growing Hidden Markov Model (GHMM) method that has been proposed to model behavior of pedestrian without observed data or with very few of them. This is achieved by building on existing work using potential cost maps and the principle of Natural Vision. As a consequence, the proposed model is able to predict pedestrian positions more precisely over a longer horizon compared to the state of the art. The method is tested over legal and illegal behavior of pedestrians, having trained the model with sparse observations and partial trajectories. The method, with no training data (see Fig. 17.a), is compared against a trained state of the art model. It is observed that the proposed method is robust even in new, previously unseen areas. This work was published in [99] and won the **best student paper** of the conference. In 2019, Pavan Vasishta defended his PhD on this topic.

7.4.2. Proactive Navigation for navigating dense human populated environments

Participants: Maria Kabtoul, Anne Spalanzani, Philippe Martinet.

Figure 17. a. Prior Topological Map of the dataset from the Traffic Anomaly Dataset : first figure shows the generated potential cost map and second figure the "Prior Topology" of the image from scene. b. Illustration of the Principle of Proactive Navigation.

Developing autonomous vehicles capable of navigating safely and socially around pedestrians is a major challenge in intelligent transportation. This challenge cannot be met without understanding pedestrians' behavioral response to an autonomous vehicle, and the task of building a clear and quantitative description of the pedestrian to vehicle interaction remains a key milestone in autonomous navigation research. As a step towards safe proactive navigation in a spaceshared with pedestrians, we start to introduce in 2018 a pedestrian-vehicle interaction behavioral model. The model estimates the pedestrian's cooperation with the vehicle in an interaction scenario by a quantitative time-varying function. Using this cooperation estimation the pedestrian's trajectory is predicted by a cooperation-based trajectory planning model (see Figure 17.b). Both parts of the model are tested and validated using real-life recorded scenarios of pedestrian-vehicle interaction. The model is capable of describing and predicting agents' behaviors when interacting with a vehicle in both lateral and frontal crossing scenarios.

7.4.3. Modelling crowds and autonomous vehicles using Extended Social Force Models

Participants: Manon Predhumeau, Anne Spalanzani, Julie Dugdale.

The focus of this work has been on the realistic simulation of crowds in shared spaces. We have developed a simulator, based on empirical studies and the state of the art, using PED-SIM software. The simulator takes into account the density of crowds, different social group structures in different contexts, inter and intra group forces, and collision avoidance strategies of pedestrians. The Social Force Model (SFM) successfully reproduces many collective phenomena in evacuations or dense crowds. However, pedestrians behaviour is context dependent and the SFM has some limitations when simulating crowds in an open environment under normal conditions. Specifically, in an urban public square pedestrians tend to expand their personal space and try to avoid dense areas to reduce the risk of collision. Based on the SFM, the proposed model splits the perception of pedestrians into a large perception zone and a restricted frontal zone to which they pay more attention. Through their perceptions, the agents estimate the crowd density and dynamically adapt their personal space. Finally, the original social force is tuned to reflect pedestrians preference of avoiding dense areas by turning rather than slowing down as long as there is enough space. Simulation results show that in the considered context the proposed approach produces more realistic behaviours than the original SFM. The simulated crowd is less dense with the same number of pedestrians and less collisions occur, which better fits the observations of sparse crowds in an open place under normal condition [40].

7.4.4. Deep Reinforcement Learning based Vehicle Navigation amongst pedestrians

Participants: Niranjan Deshpande, Anne Spalanzani, Dominique Vaufreydaz.

The objective of this work is to develop a navigation system for an autonomous vehicle in urban environments. The urban environment would consist of other road users as well including other vehicles and pedestrians. Specifically, the focus is on the decision making (behaviour planning) aspect of navigation. In this work, we propose to use Deep Reinforcement Learning as a method to learn decision making. We have developed a Deep Q-Network based agent for decision making amongst pedestrians using the SUMO simulator. This Deep Q-Network based agent is trained for a typical intersection crossing setup amongst pedestrians (see Figure 18). We propose a grid based representation as a state space input to the learning agent. With this grid based representation and our reward function the agent learns a policy capable of driving safely around pedestrians and also follow the traffic rule. This work was published in [35].

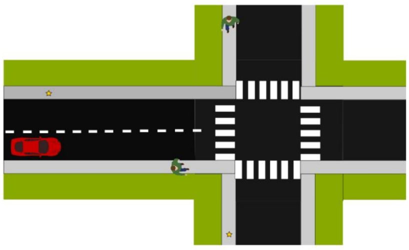

Figure 18. Typical intersection crossing used for training the behavior of the autonomous vehicle

7.5. Learning robot high-level behaviors

7.5.1. Learning task-based motion planning

Participants: Christian Wolf, Jilles Dibangoye, Laetitia Matignon, Olivier Simonin, Edward Beeching.

Our goal is the automatic learning of robot navigation in complex environments based on specific tasks and from visual input. The robot automatically navigates in the environment in order to solve a specific problem, which can be posed explicitly and be encoded in the algorithm (e.g. find all occurences of a given object in the environment, or recognize the current activities of all the actors in this environment) or which can be given in an encoded form as additional input, like text. Addressing these problems requires competences in computer vision, machine learning and AI, and robotics (navigation and paths planning).

A critical part for solving these kind of problems involving autonomous agents is handling memory and planning. An example can be derived from biology, where an animal that is able to store and recall pertinent information about their environment is likely to exceed the performance of an animal whose behavior is purely reactive. Many control problems in partially observed 3D environments involve long term dependencies and planning. Solving these problems requires agents to learn several key capacities: *spatial reasoning* — to explore the environment in an efficient manner and to learn spatio-temporal regularities and affordances. The agent needs to discover relevant objects, store their positions for later use, their possible interactions and the eventual relationships between the objects and the task at hand. Semantic mapping is a key feature in these tasks. A second feature is *discovering semantics from interactions* — while solutions exist for semantic mapping and semantic SLAM [64], [94], a more interesting problem arises when the semantics of objects and their affordances are not supervised, but defined through the task and thus learned from reward.

We started this work in the end of 2017, following the arrival of C. Wolf and his 2 year delegation in the team between Sept 2017. to Sept. 2019, through combinations of reinforcement learning and deep learning. The underlying scientific challenge here is to automatically learn representations which allow the agent to solve multiple sub problems required for the task. In particular, the robot needs to learn a metric representation (a map) of its environment based from a sequence of ego-centric observations. Secondly, to solve the problem,

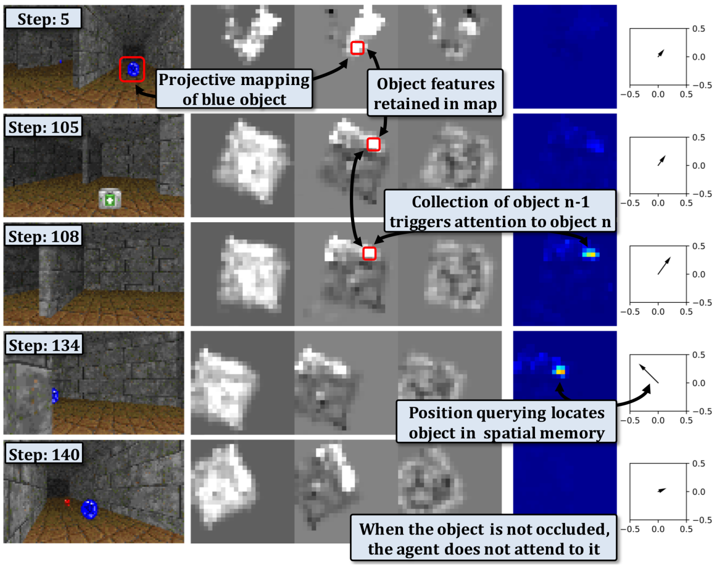

Figure 19. Analysis of the EgoMap for key steps (different rows) during an episode. Left column - RGB observations, central column - the three largest PCA components of features mapped in the spatially structured memory, right - attention heat map (result of the query) and x,y query position vector.

it needs to create a representation which encodes the history of ego-centric observations which are relevant to the recognition problem. Both representations need to be connected, in order for the robot to learn to navigate to solve the problem. Learning these representations from limited information is a challenging goal. This is the subject of the PhD thesis of Edward Beeching, which started on October 2018.

First work proposed a new 3D benchmark for Reinforcement learning, which requires high-level reasoning through the automatic discovery of object affordances [58]. Follow-up work proposed EgoMap, a spatially structured metric neural memory architecture integrating projective geometry in deep reinforcement learning, which we show to outperform classical recurrent baselines. In particular, we show that through visualizations that the agents learns to map relevant objects in its spatial memory without any supervision purely from reward (see Fig. 19). Ongoing work aims to propose a fully differentiable topological memory for Deep-RL.

Creating agents capable of high-level reasoning based on structured memory is main topic of the AI Chair "REMEMBER" obtained by C.Wolf in late 2019 and which involves O. Simonin and J. Dibangoye (Inria Chroma) as well as Laetitia Matignon (LIRIS/Univ Lyon 1). The chair is co-financed by ANR, Naver Labs Europe and INSA-Lyon.

7.5.2. Social robot : NAMO extension and RoboCup@home competition

Participants: Jacques Saraydaryan, Fabrice Jumel, Olivier Simonin, Benoit Renault, Laetitia Matignon, Christian Wolf.

Since 3 years, we investigate robot/humanoid navigation and complex tasks in populated environments such as homes :

- In 2018 we started to study NAMO problems (Navigation Among Movable Obstacles). In his PhD work, Benoit Renault is extending NAMO to Social-NAMO by modeling obstacle hindrance in regards to space access. Defining new spatial cost functions, we extend NAMO algorithms with the ability to maintain area accesses (connectivity) for humans and robots [41]. We also developed a simulator of NAMO problems and algorithms, called S-NAMO-SIM.

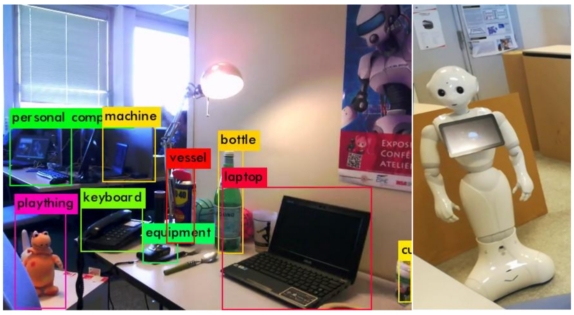

Figure 20. (a) Pepper's navigation and mapping (b) Object detection with Pepper based on vision/deep learning techniques.

- In the context of the **RoboCup** international competition, we created in 2017 the'LyonTech' team, gathering members from Chroma (INSA/CPE/UCBL). We investigated several issues to make humanoid robots able to evolve in a populated indoor environment : decision making and navigation (Fig. 20.a), human and object recognition based on deep learning techniques (Fig. 20.b) and human-robot interaction. In July 2018, we participated for the first time to the RoboCup and we reached the 5th place of the SSL league (Robocup@home with Pepper). In July 2019, we participated to the RoboCup organized in Sydney and we obtained the 3rd place of the SSL league. We also awarded the scientific Best Paper of the RoboCup conference [43].

7.6. Sequential decision-making

This research is the follow up of a subgroup led by Jilles S. Dibangoye carried out during the last four years, which include foundations of sequential decision making by a group of cooperative or competitive robots or more generally artificial agents. To this end, we explore combinatorial, convex optimization and reinforcement learning methods.

7.6.1. Optimally solving zero-sum games using centralized planning for decentralized control theory

Participants: Jilles S. Dibangoye, Olivier Buffet [Inria Nancy], Vincent Thomas [Inria Nancy], Abdallah Saffidine [Univ. New South Whales], Christopher Amato [Univ. New Hampshire], François Charpillet [Inria Nancy, Larsen team].

During the last two years, we investigated deep and standard reinforcement learning for solving systems with multiple agents and different information structures. Our preliminary results include:

1. (Theoretical) – As an extension of [68] in the competitive cases, we characterize the optimal solution of two-player fully and partially observable stochastic games.
2. (Theoretical) – We further exhibit new underlying structures of the optimal solution for both non-cooperative two-player settings with information asymmetry, one agent sees what the other does and sees.
3. (Algorithmic) – We extend a non-trivial procedure for computing such optimal solutions.

This work aims at reinforcing a recent theory and algorithms to optimally solving a two-person zero-sum POSGs (zs-POSGs). That is, a general framework for modeling and solving two-person zero-sum games (zs-Games) with imperfect information. Our theory builds upon a proof that the original problem is reducible to a zs-Game—but now with perfect information. In this form, we show that the dynamic programming theory applies. In particular, we extended Bellman equations [59] for zs-POSGs, and coined them maximin (resp. minimax) equations. Even more importantly, we demonstrated Von Neumann & Morgenstern's minimax theorem [102] [103] holds in zs-POSGs. We further proved that value functions—solutions of maximin (resp. minimax) equations—yield special structures. More specifically, the optimal value functions are Lipchitz-continuous. Together these findings allow us to extend planning techniques from simpler settings to zs-POSGs. To cope with high-dimensional settings, we also investigated low-dimensional (possibly non-convex) representations of the approximations of the optimal value function. In that direction, we extended algorithms that apply for convex value functions to lipschitz value functions.

7.6.2. Learning 3D Navigation Protocols on Touch Interfaces with Cooperative Multi-Agent Reinforcement Learning

Participants: Jilles S. Dibangoye, Christian Wolf [INSA Lyon], Quentin Debard [INSA Lyon], Stephane Canu [INSA Rouen].

During the last year, we investigated a number of real-life applications of deep multi-agent reinforcement learning techniques [34]. In particular, we propose to automatically learn a new interaction protocol allowing to map a 2D user input to 3D actions in virtual environments using reinforcement learning (RL). A fundamental problem of RL methods is the vast amount of inter- actions often required, which are difficult to come by when humans are involved. To overcome this limitation, we make use of two collaborative agents. The first agent models the human by learning to perform the 2D finger trajectories. The second agent acts as the interaction protocol, interpreting and translating to 3D operations the 2D finger trajectories from the first agent. We restrict the learned 2D trajectories to be similar to a training set of collected human gestures by first performing state representation learning, prior to reinforcement learning. This state representation learning is addressed by projecting the gestures into a latent space learned by a variational auto encoder (VAE).

7.7. Multi-Robot Routing

7.7.1. Global-local optimization in autonomous multi-vehicle systems

Participants: Guillaume Bono, Jilles Dibangoye, Laetitia Matignon, Olivier Simonin, Florian Peyreron [VOLVO Group, Lyon].

This work is part of the PhD thesis in progress of Guillaume Bono, with the VOLVO Group, in the context of the INSA-VOLVO Chair. The goal of this project is to plan and learn at both global and local levels how to act when facing a vehicle routing problem (VRP). We started with a state-of-the-art paper on vehicle routing problems as it currently stands in the literature [62]. We were surprised to notice that few attention has been devoted to deep reinforcement learning approaches to solving VRP instances. Hence, we investigated our own deep reinforcement learning approach that can help one vehicle to learn how to generalize strategies from solved instances of travelling salesman problems (an instance of VRPs) to unsolved ones.

The difficulty of this problem lies in the fact that its Markov decision process' formulation is intractable, i.e., the number of states grows doubly exponentially with the number of cities to be visited by the salesman. To gain in scalability, we build inspiration on a recent work by DeepMind, which suggests using pointer-net, i.e., a novel deep neural network architecture, to address learning problems in which entries are sequences (here cities to be visited) and output are also sequences (here order in which cities should be visited). Preliminary results are encouraging and we are extending this work to the multi-agent setting.

7.7.2. Towards efficient algorithms for two-echelon vehicle routing problems

Participants: Mohamad Hobballah, Jilles S. Dibangoye, Olivier Simonin, Elie Garcia [VOLVO Group, Lyon], Florian Peyreron [VOLVO Group, Lyon].

During the last year, Mohamad Hobballah (post-doc INSA VOLVO Chair) investigated efficient meta-heuristics for solving two-echelon vehicle routing problems (2E-VRPs) along with realistic logistic constraints. Algorithms for this problem are of interest in many real-world applications. Our short-term application targets goods delivery by a fleet of autonomous vehicles from a depot to the clients through an urban consolidation center using bikers. Preliminary results include:

1. (Methodological) Design of a novel meta-heuristic based on differential evolution algorithm [66] and iterative local search [101]. The former permits us to avoid being attracted by poor local optima whereas the latter performs the local solution improvement.
2. (Empirical) Empirical results on standard benchmarks available at http://www.vrp-rep.org/datasets.html show state-of-the-art performances on most VRP, MDVRP and 2E-VRP instances.

7.7.3. Multi-Robot Routing (MRR) for evolving missions

Participants: Mihai Popescu, Olivier Simonin, Anne Spalanzani, Fabrice Valois [INSA/Inria, Agora team].

After considering Multi-Robot Patrolling of known targets [86], we generalized to MRR (multi-robot routing) and to DMRR (Dynamic MRR) in the work of the PhD of M. Popescu. Target allocation problems have been frequently treated in contexts such as multi-robot rescue operations, exploration, or patrolling, being often formalized as multi-robot routing problems. There are few works addressing dynamic target allocation, such as allocation of previously unknown targets. We recently developed different solutions to variants of this problem :

- MRR-Sat : Multi-robot routing decentralized solutions consist in auction-based methods. Our work addresses the MRR problem and proposes MRR with saturation constraints (MRR-Sat), where the cost of each robot treating its allocated targets cannot exceed a bound (called saturation). We provided a NP-Complete proof for the problem of MRR-Sat. Then, we proposed a new auction-based algorithm for MRR-Sat and MRR, which combines ideas of parallel allocations with target-oriented heuristics. An empirical analysis of the experimental results shows that the proposed algorithm outperforms state-of-the art methods, obtaining not only better team costs, but also a much lower running time. Results are under review.
- DMRR : we defined the Dynamic-MRR problem as the continuous adaptation of the ongoing robot missions to new targets. We proposed a framework for dynamically adapting the existent robot missions to new discovered targets. Dynamic saturation-based auctioning (DSAT) is proposed for adapting the execution of robots to the new targets. Comparison was made with algorithms ranging from greedy to auction-based methods with provable sub-optimality. The results for DSAT shows it outperforms state-of-the-art methods.
- Synchronization : When patrolling targets along bounded cycles, robots have to meet periodically to exchange information, data (e.g. results of their tasks). Data will finally reach a delivery point. Hence, patrolling cycles sometimes have common points (rendezvous points), where the information needs to be exchanged between different cycles (robots). We investigated this problem by defining the following first solutions : random-wait, speed adaptation (first-multiple), primality of periods, greedy interval overlapping. In the context of the PHC 'DRONEM' project [32] we also developed a flow-based approach to the synchronization problem with the team of Prof. Gabriela Czibula from Babes-Bolyai University in Cluj-Napoca, Romania, see [37].

7.8. Multi-UAV exploration and communication

7.8.1. Multi-UAV Exploration and Visual Coverage of 3D Environments

Participants: Alessandro Renzaglia, Olivier Simonin, Jilles Dibangoye, Vincent Le Doze.

[32] Hubert Curien Partnership

Figure 21. (a) UAVs Chroma simulator (b) Intel Aero quadrotors platform (c) Crazyflie micro-UAV platform extended with UWB decawave chip.

Multi-robot teams, especially when involving aerial vehicles (UAVs [33]), are extremely efficient systems to help humans in acquiring information on large and complex environments. In these scenarios, two fundamental tasks are static coverage and exploration. In both cases, the robots' goal is to navigate through the environment and cooperate to maximize the observed area, either by finding the optimal static configuration which provides the best global view in the case of the coverage or by maximizing the new observed areas at every step until the environment becomes completely known in the case of the exploration.

Although these tasks are usually considered separately in the literature, we proposed a common framework where both problems are formulated as the maximization of online acquired information via the definition of single-robot optimization functions, which differs only slightly in the two cases to take into account the static and dynamic nature of coverage and exploration respectively [34]. A common derivative-free approach based on a stochastic approximation of these functions and their successive optimization is proposed, resulting in a fast and decentralized solution. The locality of this methodology limits however this solution to have local optimality guarantees and specific additional layers are proposed for the two problems to improve the final performance.

For the exploration problem, this resulted in a novel decentralized approach which alternates gradient-free stochastic optimization and a frontier-based approach [42] (IROS'19), [47]. Our method allows each robot to generate its own trajectory based on the collected data and the local map built integrating the information shared by its teammates. Whenever a local optimum is reached, which corresponds to a location surrounded by already explored areas, the algorithm identifies the closest frontier to get over it and restarts the local optimization. Its low computational cost, the capability to deal with constraints and the decentralized decision-making make it particularly suitable for multi-robot applications in complex 3D environments.

In the case of visual coverage, we studied how suitable initializations for the UAVs' positions can be computed offline based on a partial knowledge on the environment and how they can affect the final performance of the online measurements-based optimization. The main contribution of this work was thus to add another layer, based on the concept of Centroidal Voronoi Tessellation, to the optimization scheme in order to exploit an a priori sparse information on the environment to cover. The resulting method, taking advantages of the complementary properties of geometric and stochastic optimization, significantly improves the result of the uninitialized solution and notably reduces the probability of a far-to-optimal final configuration. Moreover, the number of iterations necessary for the convergence of the on-line algorithm is also reduced [88].

[33] Unmanned Aerial Vehicles

[34] A. Renzaglia, J. Dibangoye, V. Le Doze and O. Simonin, "A Common Optimization Framework for Multi-Robot Exploration and Coverage in 3D Environments," *sumbitted to* Journal of Intelligent & Robotic Systems, *under review*.

Both previous approaches have been tested in realistic simulations based on our extension of Gazebo, called SimuDronesGR (see Fig. 21.a). The development of this UAVs simulator, which includes realistic models of both the environment and the aerial vehicle's dynamics and sensors, is an important current activity in Chroma. Such a simulator has the fundamental role of allowing for realistic tests to validate the developed algorithms and to better prepare the implementation of these solutions on the robotic platform of the team (Intel Aero quadrotors, Fig. 21.b) for real experiments.

7.8.2. Communication-based control of swarm of UAVs

Participants: Remy Grunblatt, Olivier Simonin, Isabelle Guerin-Lassous [Inria/Lyon 1 Dante team], Alexandre Bonnefond.

Intel WiFi controllers are used in many common devices, such as laptops, but also in the Intel Aero Ready-to-Fly UAVs (Unmanned Aerial Vehicle). The mobility capabilities of these devices lead to greater dynamics in radio conditions, and therefore introduce a need for a suitable and efficient rate adaptation algorithm. In the context of the PhD of Remy Grunblatt, we have reverse-engineered the Intel rate adaptation mechanism from the source code of the IwlWifi Linux driver, and we have given, in a comprehensive form, the underlying rate adaptation algorithm named Iwl-Mvm-Rs. We have also implemented the Iwl-Mvm-Rs algorithm in the NS-3 simulator. Thanks to this implementation, we can evaluate the performance of Iwl-Mvm-Rs in different scenarios (static and with mobility, with and without fast fading). We also compared the performances of Iwl-Mvm-Rs with the ones of Minstrel-HT and IdealWifi, also implemented in the NS-3 simulator. This work has been published in ACM MSWiM conference (A) [36].

In the end of 2019, we obtained a DGA/Inria AI project, called "Dynaflock", aiming to extend the flocking approach to control swarm of communicating UAVs. Alexandre Bonnefond started a PhD to elaborate dynamic flocking models based on the link quality, which can be measured online.

7.8.3. Ultra-WideBand based localization & control of micro-UAVs fleets

Participants: Stephane d'Alu, Olivier Simonin, Oana Iova [Inria/INSA Agora team], Hervé Rivano [Inria/INSA Agora team].

The literature on autonomous flight of swarm of UAVs in indoor environments shows it requires the use of an external camera-based localization, i.e. a motion capture system. Indoor flying without such an expensive equipment installed in the infrastructure remains a challenge. To tackle this challenge, we investigate the Ultra-WideBand technology which can be embedded on micro UAVs as a way to estimate inter-drone distances (see Fig. 21.c Crazyflie micro-UAV). In our approach, the distance information is a fundamental building block to perform a self-maintaining formation flight. We defined and experimented a time-of-flight distance computation, using UWB decawave chips. We showed a Crazyflie flying and computing its position in function of three fixed anchors. We also tested a two-UAV flight where inter-distance is measured to avoid collisions. See first results in [33].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. VOLVO-Renault Trucks Group (2016-2019)

Participants: Olivier Simonin, Jilles Dibangoye, Guillaume Bono, Mohamad Hobballah, Laetitia Matignon.

This collaboration has been built inside the INSA-VOLVO Chair, led by Prof. Didier Remond (INSA). In this context, the Chair funds the PhD Thesis of Guillaume Bono (2016-19) in Chroma. The objective is to study how machine learning techniques can deal with optimization of goods distribution using a fleet of autonomous vehicles. In the following of the first results, VOLVO proposed to extend our collaboration by funding a Post-doc position concerning good distribution with platoons of autonomous vehicles. This is the Post-Doc of Mohamad Hobballah, started on February 2018.

8.1.2. Toyota Motor Europe (2006 - 2018)

Participants: Christian Laugier, David Sierra González, Özgür Erkent, Jilles Dibangoye, Christian Wolf.

The contract with Toyota Motors Europe is a joint collaboration involving Toyota Motors Europe, Inria and ProbaYes. It follows a first successful short term collaboration with Toyota in 2005. This contract aims at developing innovative technologies in the context of automotive safety. The idea is to improve road safety in driving situations by equipping vehicles with the technology to model on the fly the dynamic environment, to sense and identify potentially dangerous traffic participants or road obstacles, and to evaluate the collision risk. The sensing is performed using sensors commonly used in automotive applications such as cameras and lidar.

This collaboration has been extended in 2018 for 4 years (period 2018-2021) and Toyota provides us with an experimental vehicle Lexus equipped with various sensing and control capabilities. Several additional connected technical contracts have also been signed, and an exploitation licence for the *CMCDOT* software has been bought by Toyota in 2018.

8.2. Bilateral Grants with Industry

8.2.1. Renault (2015 - 2018)

Participants: Mathieu Barbier, Christian Laugier, Olivier Simonin.

This contract was linked to the PhD Thesis of Mathieu Barbier (Cifre Thesis). The objective is to develop technologies for collaborative driving as part of a Driving Assistance Systems for improving car safety in road intersections. Both vehicle perception and communications are considered in the scope of this study. Some additional short-term contracts (about 3 months) and an evaluation license for the team *CMCDOT* software have also been signed during this period. *We are on the process of signing a new PhD research agreement for the period 2019 – 2021, with objective to address the open problem of emergency obstacle avoidance in complex traffic situations (for ADAS or AD applications).*

8.2.2. IRT Nanoelec – Security of Autonomous Vehicles project (2018 - 2020)

Participants: Christian Laugier, Lukas Rummelhard, Jerome Lussereau, Jean-Alix David, Thomas Genevois, Nicolas Turro [SED].

Security of Autonomous Vehicles is a project supported by ANR in the scope of the program PULSE of IRT Nanoelec. The objective of this project is to integrate, develop and promote technological bricks of context capture, for the safety of the autonomous vehicle. Building on *Embedded Bayesian Perception for Dynamic Environment*, Bayesian data fusion and filtering technologies from sets of heterogeneous sensors, these bricks make it possible to secure the movements of vehicles, but also provide them with an enriched and useful representation for autonomy functions themselves. In this context, various demonstrators embedding those technology bricks are developed in cooperation with industrial partners.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. Inria ADT 'CORDES' (2017-19) & 'COLOC' (2019-20)

Participants: Olivier Simonin, Vincent Le Doze, Jilles Dibangoye, Alessandro Renzaglia.

The COLOC ADT, which follows the CORDES ADT, aims to coordinate a team of UAVs using both SLAM techniques and communication-based localization, considering outdoor urban environments. These ADT are coordinated by Olivier Simonin. They fund an Inria expert engineer position in Chroma (Vincent Le Doze, 10/17-11/20) focusing on UAVs control and localization. The project provides both a 3D simulator of UAV fleets (SimuDronesGR) and a new experimental platform exploiting IntelAero UAVs.

9.1.2. COMODYS project, FIL (Federation d'Informatique de Lyon), 2017-19

Participants: Laetitia Matignon, Olivier Simonin.

Project between two teams of two laboratories from Lyon : CHROMA (CITI) and SMA (LIRIS), entitled "COoperative Multi-robot Observation of DYnamic human poSes", 2017-2019. Leader : L. Matignon & O. Simonin.

This project funds materials, missions and internships and its objectives are the on-line adaptation of a team of robots that observe and must recognize human activities.

9.1.3. WIFI-Drones project, FIL (Federation d'Informatique de Lyon), 2019-21

Participants: Remy Grunblatt, Isabelle Guerin-Lassous [Inria/Lyon1 Dante team], Olivier Simonin.

Project between two teams of two laboratories from Lyon : DANTE (LIP) and CHROMA (CITI), entitled "*Performances des communications Wi-Fi dans les réseaux de drones : une approche expérimentale*", 2019-2021. Leader : I. Guerin-Lassous & O. Simonin.

The project aims to experimentally evaluate the Wireless communication in UAVs fleet scenarios. We consider the recent version of Wi-Fi based on 802.11n and 802.11 ac. Experimental measures will be used to build propagation models in order to be integrated in UAVs fleet simulations (in particular with Gazebo and NS3 simulators).

9.2. National Initiatives

9.2.1. ANR

9.2.1.1. ANR JCJC "Plasma" (2019-2023)

The ANR JCJC Plasma, led by Jilles S. Dibangoye, aims at developing a general theory and algorithms with provable guarantees to treat planning and (deep) RL problems arising from the study of multi-agent sequential decision-making, which may be described as Partially Observable Stochastic Games (POSG), see Figure 1. We shall contribute to the development of theoretical foundations of the fields of intelligent agents and MASs by characterizing the underlying structure of the multi-agent decision-making problems and designing scalable and error-bounded algorithms. The research group is made of four senior researchers, O. Simonin, C. Wolf (INSA Lyon), F. Charpillet (Inria Nancy) and O. Buffet (Inria Nancy), and two junior researchers Jilles S. Dibangoye and A. Saffidine (Univeristy of New South Whales). We plan to hire one PhD and one post-doc for two years as well as internships. We received a support for 42-months starting in March 2020 with a financial support of about 254 269,80 euros.

9.2.1.2. ANR "Delicio" (2019-2023)

The ANR Delicio, led by C. Wolf (INSA Lyon, LIRIS), proposes fundamental and applied research in the areas of Machine Learning and Control with applications to drone (UAV) fleet control. The consortium is made of 3 academic partners: INSA-Lyon/LIRIS (C. Wolf and L. Matignon), INSA-Lyon/CICI (J. Dibangoye, O. Simonin, and I. Redko), University Lyon 1/LAGEPP (M. Nadri, V. Andrieu, D. Astolfi, L. bako, and G. Casadei), and ONERA (S. Bertrand, J. Marzat, H. Piet-Lahanier). We plan to hire two Ph.D and two post-doc for one year as well as interships. We received a support for 48-months starting in October 2019 with a financial support of about 540 000 euros.

9.2.1.3. ANR "Valet" (2016-19)

The ANR VALET, led by A. Spalanzani, proposes a novel approach for solving the 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 consortium is made of 2 academic partners: Inria (RITS, Chroma, Prima) and Irccyn Ecole Centrale de Nantes and the AKKA company. The PhD student (Pavan Vashista) recruited in this project focuses on integrating models of human behaviors to evaluate and communicate a risk to pedestrians that may encounter the trajectory of the VALET vehicle. His PhD thesis, codirected by D. Vaufreydaz (Inria/PervasiveInteraction), has been defended in June 2019.

9.2.1.4. ANR "HIANIC" (2017-21)

The HIANIC project, led by A. Spalanzani, proposes to endow autonomous vehicles with smart behaviors (cooperation, negotiation, socially acceptable movements) that better suit complex SharedSpace situations. It will integrate models of human behaviors (pedestrian, crowds and passengers), social rules, as well as smart navigation strategies that will manage interdependent behaviors of road users and of cybercars. The consortium is made of 3 academic partners: Inria (RITS, Chroma, Pervasive Interaction teams), LIG Laboratory (Hawai team) and LS2N laboratory (ARMEN and PACCE teams).

9.2.1.5. PIA Ademe "CAMPUS" (2017-20)

The CAMPUS project aims to identify, develop and deploy new functions for the autonomous cars in urban environments. In this project, Chroma will focus on finding solutions to navigate in complex situations such as crowded environments or dense traffic. The consortium is made of 1 academic partner: Inria (Rits and Chroma teams) and 3 companies: Safran electronics, Gemalto and Valeo.

9.2.2. FUI Projects

9.2.2.1. FUI Tornado (2017 – 2020)

Participants: Rabbia Asghar, Anne Spalanzani, Christian Laugier, Olivier Simonin.

The project Tornado is coordinated by Renault. The academic partners of the project are Inria Grenoble-Rhône Alpes, UTC, Institut Pascal, University of Pau, IFSTTAR. The industrial and application partners are Renault, Easymile, Neavia, Exoskills, 4D-Virtualiz, MBPC and Rambouillet Territoires. The objective of the project is to demonstrate the feasibility of a mobility service systems operating in the commercial zone of Rambouillet and on some public roads located in its vicinity, with several autonomous cars (Autonomous Renault Zoe). The *IRT Nanoelec* is also involved in the project as a subcontractor, for testing the perception, decision-making, navigation and controls components developed in the project.

9.2.2.2. FUI STAR (2018 – 2021)

Participants: Andres Gomez Hernandez, Olivier Simonin, Christian Laugier.

The Project STAR is coordinated by IVECO. The academic partners of the project are Inria Grenoble-Rhône-Alpes, IFSTTAR, ISAE-Supaéro. The industrial and application partners are IVECO, Easymile, Transpolis, Transdev and Sector Groupe. The goal of the project is to build an autonomous bus that will operate on a safe lane Inria is involved in helping design situation awareness perception, especialy in special case like docking at the bus stop and handling dynamicity of any obstacle. The *IRT Nanoelec* is also involved in the project as a subcontractor, for testing the perception, decision-making, navigation and controls components developed in the project.

9.2.3. DGA/Inria AI projects

9.2.3.1. "DYNAFLOCK" (2019-2023)

The DYNAFLOCK project, led by O. Simonin, aims to extend flocking-based decentralized control of swarm of UAVs by considering the link quality between communicating entities. The consortium is made of 2 Inria teams from Lyon : Chroma and Dante (involving Prof. I. Guerin-Lassous). The PhD student (Alexandre Bonnefond) recruited in this project aims at defining dynamic flocking models based on the link quality. In 2020, an engineer will be recruited to conduct experiments with a quadrotors platform.
Funding of Dynaflock : $\sim$ 250 K€.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. ICT Robotics project "BugWright2" (2020-23)

Success for European H2020 ICT Robotics project application 'BugWright2' (9M€), led by C. Pradalier (CNRS, GeorgiaTech Metz). Chroma is partner and responsible of WP6.

Title : Autonomous Robotic Inspection and Maintenance on Ship Hulls and Storage Tanks

1/01/2020 - 31/12/2023

O. Simonin leads the Multi-Robot Systems work-package (WP6). Chroma will work on multi-robot planning and experiment under environmental constraints. The Agora team is also involved (H. Rivano, O. Iova) to work on robot localization based on the Ultra-WideBand technology.

Funding for Chroma & Agora teams : 600K€

http://dream.georgiatech-metz.fr/research-projects/bugwright2/

9.3.2. Collaborations with Major European Organizations

- ETHZ, Zurich, Autonomous System laboratory, (Switzerland)
- University of Zurich, Robotics and Perception Group (Switzerland) Vision and IMU data Fusion for 3D navigation in GPS denied environment.
- Karlsruhe Institut fur Technologie (KIT, Germany) Autonomous Driving.
- University of Babes-Bolyai, Cluj-Napoca (Romania). Multi-robot patrolling and Machine Learning (PHC "DRONEM" 2017-18).
- Vislab Parma (Italy) Embedded Perception & Autonomous Driving (visits, projects submissions, and book chapter in the new edition of the Handbook of Robotics).

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

10.1.1.1. General Chair, Scientific Chair

- C. Laugier was General Co-Chair of IEEE/RSJ IROS [35] 2019 (Macau, Nov 2019).
- C. Laugier co-organized in the scope of IEEE/RSJ IROS 2019 and of the IEEE RAS Technical Committee IGV-ITS, the 11th Workshop of the series PPNIV (Planning, Perception and Navigation for Intelligent Vehicles) having attracted about 300 people (see http://project.inria.fr/ppniv19 for more details).
- C. Laugier co-organized at IEEE/RSJ IROS 2019 a Cutting Edge Forum on "Robotics, AI and ITS for Autonomous Driving" having attracted about 150 people (see https://project.inria.fr/ad19/ for more details).
- O. Simonin was General Co-Chair and Co-Organizer with F. Charpillet (Inria Nancy) of the JNRR 2019 conference, the bi-annual conference gathering the French Robotic community, in Vittel (∼ 200 pers.) October 15-17 2019. https://jnrr2019.loria.fr/
- O. Simonin was General and Scientific Chair of JFSMA 2019 (*27emes Journées Francophones sur les Systèmes Multi-Agents*), in Toulouse, as part of PFIA 2019 (Plate-forme IA), July 1-5 2019. https://www.irit.fr/pfia2019/jfsma/

[35] IEEE/RSJ International Conference on Intelligent Robots and Systems

10.1.1.2. Member of the Organizing Committees

- Agostino Martinelli was in the organizing committee of the workshop on “visual-inertial navigation: challenges and applications”, held during IROS 2019 in Macau, China.
- C. Laugier was Member of the Organizing Committee of the conference IEEE CIS-RAM 2019 (Bangkok, Nov 2019).
- J. S. Dibangoye and O. Simonin were Members of the Organizing Committee of IA^2 – Institut d’Autonomne en Intelligence Artificielle, Lyon 2019.

10.1.2. Scientific Events: Selection

10.1.2.1. Chair of Conference Program Committees

- O. Simonin was Chair of JFSMA Program Committee (27emes journées francophones sur les systèmes multi-agents), Toulouse, France, July 3-5, 2019. He co-edited with S. Combettes (IRIT/Toulouse) the JFSMA 2019 Proceedings, Cépaduès 2019, ISBN 9782364937192.

10.1.2.2. Member of the Conference Program Committees

- C. Laugier served as Associate Editor for the conference IEEE ICRA 2019 (Montreal, May 2019) and also for IEEE ICRA 2020 (Paris, May 2020).
- C. Laugier served as member of the Senior Program Committee of IEEE/RSJ IROS 2019 (Macau, Nov 2019).
- A. Martinelli was Associate Editor for IEEE ICRA 2020.
- A. Spalanzani was PC member of the ECAI 2019 conference.
- J. S. Dibangoye was Senior PC member of the ECAI 2019 conference.
- J. S. Dibangoye was PC member of the IJCAI 2019 conference.
- J. S. Dibangoye was PC member of the AAAI 2020 conference.
- J. S. Dibangoye was PC member of the NeurIPS 2019 conference (selected as one of the best reviewers).
- J. S. Dibangoye was PC member of the PKDD-ECML 2019 conference.
- J. S. Dibangoye was PC member of the JFPDA 2019 conference.
- O. Simonin was Senior PC member of the ECAI 2019 conference.
- O. Simonin was PC member of the IJCAI 2019 conference.
- O. Simonin was PC member of the AAAI 2020 conference.
- O. Simonin was PC member of the ICAPS 2019 conference - Robotics Track (29th International Conference on Automated Planning and Scheduling).
- O. Simonin was PC member of the ECMR 2019 conference (European Conference on Mobile Robots).

10.1.2.3. Reviewer

- A. Martinelli served, in quality of reviewer, for the following conferences: ICRA.
- O. Simonin served, in quality of reviewer, for the following conferences: IROS, ICRA.
- J. S. Dibangoye served, in quality of reviewer, for the following conferences: CDC, ACC, AAMAS, JFPDA.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- C. Laugier is Member of the Steering Committee of the journal IEEE Transaction on Intelligent Vehicles.
- C. Laugier is Senior Editor of the journal IEEE Transaction on Intelligent Vehicles

- C. Laugier is member of the Editorial Board of the journal IEEE ROBOMECH.
- O. Simonin was member of the Editorial Board of RIA revue (*Revue d'Intelligence Artificielle*), from 1/1/2018 to 1/06/2019. He is now member of the Editorial Board of the new revue ROIA (*Revue Ouverte d'Intelligence Artificielle*).

10.1.3.2. Reviewer - Reviewing Activities

- Agostino Martinelli served, in quality of reviewer, for the following journals: Transaction on Automatic Control, Automatica, Journal of Robust Control, Transaction on Robotics.
- O. Simonin was reviewer for SMCA journal (Systems, Man and Cybernetics: System).
- O. Simonin was reviewer for RIA revue (Revue d'Intelligence Artificielle).
- J. S. Dibangoye was reviewer for AIJ (Artificial Intelligence Journal).
- J. S. Dibangoye was reviewer for JAIR (Journal of Artificial Intelligence Research).
- J. S. Dibangoye was reviewer for JMLR (Journal of Machine Learning Research).
- J. S. Dibangoye was reviewer for TAC (IEEE Transaction on Automatic Control).

10.1.4. Invited Talks

- J. S. Dibangoye gave an invited talk at the Czech technical University in Prague, Czech Republic, in July 2019.
- J. S. Dibangoye gave an invited talk at the MAFTEC working group of GdR IA, in Caen, France, in February 2019.
- C. Laugier gave an invited talk at the conference IS Auto Europe 2019, Berlin, April 2019. Title: Embedded Sensor Fusion and Perception for Autonomous Vehicles.
- C. Laugier gave an invited talk at the conference IS Auto Europe 2019, Berlin, April 2019. Title: Embedded Sensor Fusion and Perception for Autonomous Vehicles.
- C. Laugier gave an invited talk at the Technological Conference Minalogic B2B 2019, Grenoble, May 2019. Title: Mixing Bayesian and AI approaches for Autonomous Driving.
- C. Laugier gave an invited keynote talk at the conference IEEE World Robotics Conference WRC 2019, Beijing, August 2019. Title: Impact of AI on Autonomous Driving.
- C. Laugier gave an invited Pioneer's talk at the conference IEEE/RSJ IROS 2019, Macau, November 2019. Title: A Journey in the history of Automated Driving.
- C. Laugier gave an invited keynote talk at the Cutting Edge Forum "Robotics, AI and ITS for Autonomous Driving", Conference IEEE/RSJ IROS 2019, Macau, November 2019. Title: Situation Awareness and Decision-making for Autonomous Driving.
- A. Martinelli gave the invited talk "Nonlinear Unknown Input Observability: the General Analytic Solution" on behalf of the Automatic Control Laboratory and the Institute for Dynamic Systems and Control at the ETHZ of Zurich, May, 6, 2019
- A. Martinelli gave invited talk "Nonlinear Unknown Input Observability: the General Analytic Solution" at La Sapienza University, Control lab, Rome, November, 29, 2019
- A. Spalanzani gave a talk that the "Journées Nationales de la Recherche en Robotique" (JNRR) in October 2019.
- O. Simonin gave an invited talk at the GdR Robotics Winter School: Robotica Principia "Decision making in robotics", Centre de recherche Inria Sophia Antipolis – Méditérranée, France. January 21-25, 2019, [55].
- O. Simonin gave an invited talk at the GdR IA2 Autumn School: "Introduction à la coordination multi-agent", CITI Lab/INSA Lyon.

10.1.5. Leadership within the Scientific Community

- C. Laugier is co-chair with Philippe Martinet, Marcelo Ang and Denis Wolf of the IEEE RAS Technical Committee on "Autonomous Ground Vehicles and Intelligent Transportation Systems (AGV-ITS)". He founded this IEEE RAS TC about 15 years ago, as a bridge between the RAS and ITS societies of IEEE.
- C. Laugier is member of the Steering Committee of IEEE/RSJ IROS.
- C. Laugier is member of the Scientific Committee of the French GDR Robotique.
- C. Laugier is member of several International Award Committees for IEEE RAS (Chapter Award Committee) and for IEEE/RSJ IROS.
- O. Simonin is member of the Board of AFIA "*Association Française pour l'Intelligence Artificielle*" (https://afia.asso.fr/).

10.1.6. Scientific Expertise

- O. Simonin was member of the HCERES committee of LIG lab.
- C. Laugier is member of the Advisory Board of ISR University of Coimbra.
- C. Laugier is Scientific Advisor for the Probayes SA and for Baidu China.

10.1.7. Research Administration

- C. Laugier is a member of several Ministerial and Regional French Committees on Robotics and Autonomous Cars.
- A. Spalanzani was a member of the committee of the ANR project selection in Mobilité et systèmes urbains durables.
- A. Spalanzani was a member of the GDR best Robotics PhD thesis committee.
- O. Simonin is member of the Auvergne-Rhone-Alpes Robotics cluster (Coboteam), for Inria and INSA Lyon entities.
- O. Simonin is member of the Scientific Council of the Digital League (Auvergne-Rhone-Alpes).

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

INSA Lyon 5th year : O. Simonin, Resp. of the Robotics option (25 students): AI for Robotics, Multi-Robot Systems, Robotics Projects, 90h, M2, Telecom Dept., France.

INSA Lyon 3rd year : O. Simonin, Resp. of Introduction to Algorithmics, 32h (100 students), L3, Telecom Dept., France.

INSA Lyon 3rd year : Jilles S. Dibangoye, Algorithmics, 24h, L3, Dept. Telecom INSA Lyon, France.

INSA Lyon 3rd year : Jilles S. Dibangoye, WEB, 42h, L3, Dept. Telecom INSA Lyon, France.

INSA Lyon 3rd year : Jilles S. Dibangoye, Operating Systems, 56h, L3, Dept. Telecom INSA Lyon, France.

INSA Lyon 4rd year : Jilles S. Dibangoye, Operating Systems, 16h, Master, Dept. Telecom INSA Lyon, France.

INSA Lyon 5th year : Jilles S. Dibangoye, the Robotics option : AI for Robotics, Robotics projects, 8h, M2, Dept. Telecom INSA Lyon, France.

M2R MoSIG: A. Martinelli, Autonomous Robotics, 12h, ENSIMAG Grenoble.

Master : Laetitia Matignon, Multi-Agents and Self-* Systems, 10h TD, M2 Artificial Intelligence, Lyon 1 University, France.

Master : Laetitia Matignon, Multi-Robot Systems, 20h TD, 5th year of engineer, Polytech Lyon Informatics Department, France.

CPE Lyon 4-5th year : F. Jumel, resp. of the Robotics option, 400h M1/ M2, Dept. SN CPE Lyon France.

CPE Lyon 4-5th year : F. Jumel, 250h (robotic vision, cognitive science, Interface robot machine, deeplearning, Robotic frameworks, robotic plateforms, Kalman Filter)

10.2.2. Supervision

PhD: David Sierra Gonzalez, Towards Human-Like Prediction and Decision-Making for Automated Vehicles in Highway Scenarios, Université Grenoble Alpes, Defended April 1st 2019, C. Laugier, J. Dibangoye, E. Mazer (Inria Pervasive Interaction).

PhD: Pavan Vasishta, Building and Leveraging Prior Knowledge for Predicting Pedestrian Behaviour Around Autonomous Vehicles in Urban Environments, Université Grenoble Alpes, Defended September 30th 2019, A. Spalanzani and D. Vaufreydaz (Inria Pervasive Interaction).

PhD: Mathieu Barbier, Decision making for Intelligent Vehicles, Defended December 11st 2019, C. Laugier, O. Simonin and E. Mazer (Inria Pervasive Interaction).

PhD in progress: Mihai Popescu, Robot fleet mobility under communication constraints, O. Simonin, A. Spalanzani, F. Valois (CITI/Inria Agora).

PhD in progress: Guillaume Bono, Global-local Optimization Under Uncertainty for Goods Distribution Using a Fleet of Autonomous Vehicles, 2016, O. Simonin, J. Dibangoye, L. Matignon.

PhD in progress: Remy Grunblatt, Mobilité contrôlée dans les réseaux de drones autonomes", 2017, I. Guerrin-Lassous (Inria Dante) and O. Simonin.

PhD in progress: Maria Kabtoul, Proactive Navigation in dense crowds, A. Spalanzani and P. Martinet (Inria Chorale).

PhD in progress: Benoit Renault, Navigation coopérative et sociale de robots mobiles en environnement modifiable, O. Simonin and J. Saraydaryan.

PhD in progress: Edward Beeching, Large-scale automatic learning of autonomous agent behavior with structured deep reinforcement learning, C. Wolf, O. Simonin and J. Dibangoye.

PhD in progress: Manon Prédhumeau, Crowd simulation and autonomous vehicle, A. Spalanzani and J. Dugdale (LIG).

Starting PhD: Luiz Serafim-Guardini, Conduite Automobile Autonome : Utilisation de grilles d'occupation probabilistes dynamiques pour la planification contextualisée de trajectoire d'urgence à criticité minimale, A. Spalanzani, C. Laugier, P. Martinet (Inria Chorale).

Starting PhD: Alexandre Bonnefond, Large-scale automatic learning of autonomous agent behavior with structured deep reinforcement learning, O. Simonin and I. Guerrin-Lassous (Inria Dante).

Starting PhD: Estéban Carvalho, Safe and aggressive piloting of UAVs, 2019, Ahmad Hably (Gipsa-Lab), Nicolas Marchand (Gipsa-Lab), Jilles S. Dibangoye.

10.2.3. Juries

HDR :

O. Simonin was reviewer and member of the defense committee of the HDR of Charles Lesire (ONERA-ISAE), INP Toulouse, "Architectures délibératives pour la robotique autonome, des algorithmes au logiciel embarqué", March 5th, 2019.

O. Simonin was reviewer and member of the defense committee of the HDR of Abbas-Turki Abdeljalil (UTBM), Université de Haute-Alsace, "Méthodes, modèles et outils pour la régulation coopérative : Application aux véhicules autonomes et connectés", December 10th, 2019.

PhD thesis :

A. Spalanzani was reviewer and member of the defense committee of the PhD thesis of José Mendes Filho, école nationale supérieure de techniques avancées, December 19th, 2019.

O. Simonin was reviewer and member of the defense committee of the PhD thesis of Nicolas Cambier, Université de Technologie de Compiègne (UTC), October 23th, 2019.

O. Simonin was reviewer and member of the defense committee of the PhD thesis of Christophe Reymann, INSA Toulouse, July 8th, 2019.

O. Simonin was member of the defense committee of the PhD thesis of Rustem Abdrakhmanov, Université Clermont Auvergne, June 27th, 2019.

O. Simonin was member of the defense committee of the PhD thesis of Bilel Chenchana, Université de Limoges, March 22th, 2019.

Jilles S. Dibangoye was member of the defense committee of the PhD thesis of Jonathan Cohen, Univ. Caen, June 13th 2019.

C. Laugier and J. Dibangoye were members of the defense committee and co-supervisor of the PhD thesis of David Sierra Gonzalez, UGA Grenoble, April 1st 2019.

C. Laugier and O. Simonin were members of the defense committee and co-supervisor of the PhD thesis of Mathieu Barbier, UGA Grenoble, December 11th 2019.

10.3. Popularization

A. Spalanzani made a cross interview on women in robotics (https://www.inria.fr/centre/nancy/actualites/une-carriere-en-robotique-regards-croises-sur-des-parcours-d-exception)

10.3.1. Articles and contents

O. Simonin gave an interview to Le Monde Informatique - IT Tour à Lyon "*La voiture autonome : mythe ou réalité ?*" (https://www.lemondeinformatique.fr/actualites/lire-interview-video-olivier-simonin-professeur-inria-insa-lyonetgrenoble-77605.html) (26/09/19)

10.3.2. Education

A. Spalanzani made a seminar on "social autonomous vehicle navigation" in the scope of "cycle de conférences ISN".

11. Bibliography

Major publications by the team in recent years

[1] M. Andries, O. Simonin, F. Charpillet. *Localisation of humans, objects and robots interacting on load-sensing floors*, in "IEEE Sensors Journal", 2015, vol. PP, n^o 99, 12 p. [*DOI :* 10.1109/JSEN.2015.2493122], https://hal.inria.fr/hal-01196042

[2] A. Broggi, A. Zelinsky, U. Ozguner, C. Laugier. *Handbook of Robotics 2nd edition, Chapter 62 on "Intelligent Vehicles"*, in "Handbook of Robotics 2nd Edition", B. Siciliano, O. Khatib (editors), Springer Verlag, July 2016, https://hal.inria.fr/hal-01260280

[3] J. S. Dibangoye, C. Amato, O. Buffet, F. Charpillet. *Optimally Solving Dec-POMDPs as Continuous-State MDPs*, in "Journal of Artificial Intelligence Research", February 2016, vol. 55, pp. 443-497 [*DOI :* 10.1613/JAIR.4623], https://hal.inria.fr/hal-01279444

[4] Ö. ERKENT, C. WOLF, C. LAUGIER, D. SIERRA GONZÁLEZ, V. R. CANO. *Semantic Grid Estimation with a Hybrid Bayesian and Deep Neural Network Approach*, in "IROS 2018 - IEEE/RSJ International Conference on Intelligent Robots and Systems", Madrid, Spain, IEEE, October 2018, pp. 1-8, https://hal.inria.fr/hal-01881377

[5] A. MARTINELLI. *State Observability in Presence of Disturbances: the Analytic Solution and its Application in Robotics*, in "IROS 2017 - IEEE/RSJ International Conference on Intelligent Robots and Systems", Vancouver, Canada, September 2017, pp. 1-8, https://hal.inria.fr/hal-01669046

[6] L. MATIGNON, O. SIMONIN. *Multi-Robot Simultaneous Coverage and Mapping of Complex Scene - Comparison of Different Strategies*, in "AAMAS 2018 - 17th International Conference on Autonomous Agents and Multiagent Systems - Robotics Track", Stockholm, Sweden, M. DASTANI, G. SUKTHANKAR, E. ANDRE, S. KOENIG (editors), ACM, July 2018, pp. 559-567, https://hal.archives-ouvertes.fr/hal-01726120

[7] A. RENZAGLIA, J. S. DIBANGOYE, V. LE DOZE, O. SIMONIN. *Combining Stochastic Optimization and Frontiers for Aerial Multi-Robot Exploration of 3D Terrains*, in "IROS 2019 - IEEE/RSJ International Conference on Intelligent Robots and Systems", Macau, China, November 2019, https://hal.inria.fr/hal-02164806

[8] J. RIOS-MARTINEZ, A. SPALANZANI, C. LAUGIER. *From Proxemics Theory to Socially-Aware Navigation: A Survey*, in "International Journal of Social Robotics", April 2015 [*DOI :* 10.1007/s12369-014-0251-1], https://hal.inria.fr/hal-01067278

[9] D. SIERRA GONZÁLEZ, V. ROMERO-CANO, J. STEEVE DIBANGOYE, C. LAUGIER. *Interaction-Aware Driver Maneuver Inference in Highways Using Realistic Driver Models*, in "Proceedings of the 2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC 2017)", Yokohama, Japan, October 2017, https://hal.inria.fr/hal-01589493

[10] P. VASISHTA, D. VAUFREYDAZ, A. SPALANZANI. *Building Prior Knowledge: A Markov Based Pedestrian Prediction Model Using Urban Environmental Data*, in "ICARCV 2018 - 15th International Conference on Control, Automation, Robotics and Vision (BEST Student Paper)", Singapore, Singapore, November 2018, pp. 1-12, https://hal.inria.fr/hal-01875147

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] M. BARBIER. *Crossing of Road Intersections: Decision-Making Under Uncertainty for Autonomous Vehicles*, Comue Université Grenoble Alpes, December 2019, https://hal.inria.fr/tel-02424655

[12] D. SIERRA GONZÁLEZ. *Towards Human-Like Prediction and Decision-Making for Automated Vehicles in Highway Scenarios*, Université Grenoble Alpes, April 2019, https://tel.archives-ouvertes.fr/tel-02184362

[13] P. VASISHTA. *Building and Leveraging Prior Knowledge for Predicting Pedestrian Behaviour Around Autonomous Vehicles in UrbanEnvironments*, Inria Grenoble Rhône-Alpes, Université de Grenoble, September 2019, https://hal.archives-ouvertes.fr/tel-02401123

Articles in International Peer-Reviewed Journals

[14] L. BRIÑÓN-ARRANZ, A. RENZAGLIA, L. SCHENATO. *Multi-Robot Symmetric Formations for Gradient and Hessian Estimation with Application to Source Seeking*, in "IEEE Transactions on Robotics", June 2019, vol. 35, n$^{\text{o}}$ 3, pp. 782-789 [*DOI :* 10.1109/TRO.2019.2895509], https://hal.inria.fr/hal-01991153

[15] Ö. ERKENT, C. WOLF, C. LAUGIER. *End-to-End Learning of Semantic Grid Estimation Deep Neural Network with Occupancy Grids*, in "Unmanned systems", July 2019, vol. 7, n$^{\text{o}}$ 3, pp. 171-181 [*DOI :* 10.1142/S2301385019410036], https://hal.archives-ouvertes.fr/hal-02302533

[16] F. JUMEL. *Advancing Research at the RoboCup@Home Competition [Competitions]*, in "IEEE Robotics and Automation Magazine", June 2019, vol. 26, n$^{\text{o}}$ 2, pp. 7-9 [*DOI :* 10.1109/MRA.2019.2908571], https://hal.archives-ouvertes.fr/hal-02305530

[17] A. MARTINELLI. *Nonlinear Unknown Input Observability: Extension of the Observability Rank Condition*, in "IEEE Transactions on Automatic Control", January 2019, vol. 64, n$^{\text{o}}$ 1, pp. 222 - 237 [*DOI :* 10.1109/TAC.2018.2798806], https://hal.archives-ouvertes.fr/hal-01966303

[18] A. MARTINELLI. *Cooperative Visual-Inertial Odometry: Analysis of Singularities, Degeneracies and Minimal Cases*, in "IEEE Robotics and Automation Letters", 2020, pp. 1-11, forthcoming, https://hal.inria.fr/hal-02427991

[19] A. MARTINELLI, A. OLIVA, B. MOURRAIN. *Cooperative Visual-Inertial Sensor Fusion: the Analytic Solution*, in "IEEE Robotics and Automation Letters", 2019, vol. 4, n$^{\text{o}}$ 2, pp. 453-460 [*DOI :* 10.1109/LRA.2019.2891025], https://hal.archives-ouvertes.fr/hal-01966542

[20] A. MARTINELLI, A. RENZAGLIA, A. OLIVA. *Cooperative Visual-Inertial Sensor Fusion: Fundamental Equations and State Determination in Closed-Form*, in "Autonomous Robots", 2019, pp. 1-19, forthcoming [*DOI :* 10.1007/S10514-019-09841-8], https://hal.inria.fr/hal-02013869

[21] P. R. PALAFOX, M. GARZÓN, J. VALENTE, J. J. ROLDÁN, A. BARRIENTOS. *Robust Visual-Aided Autonomous Takeoff, Tracking, and Landing of a Small UAV on a Moving Landing Platform for Life-Long Operation*, in "Applied Sciences", July 2019, vol. 9, n$^{\text{o}}$ 13, 2661 p. [*DOI :* 10.3390/APP9132661], https://hal.inria.fr/hal-02293315

[22] A. RENZAGLIA, L. BRIÑÓN-ARRANZ. *Search and Localization of a Weak Source with a Multi-Robot Formation*, in "Journal of Intelligent and Robotic Systems", 2019, pp. 1-12 [*DOI :* 10.1007/S10846-019-01014-0], https://hal.inria.fr/hal-02068180

[23] J. J. ROLDÁN, V. DÍAZ-MAROTO, J. REAL, P. R. PALAFOX, M. GARZÓN, J. VALENTE, A. BARRIENTOS. *Press Start to Play: Classifying Multi-Robot Operators and Predicting Their Strategies through a Videogame*, in "Robotics", September 2019, vol. 8, n$^{\text{o}}$ 3, pp. 1-14 [*DOI :* 10.3390/ROBOTICS8030053], https://hal.inria.fr/hal-02293309

[24] S. SIERRA M., M. GARZÓN, M. MUNERA, C. CIFUENTES. *Human–Robot–Environment Interaction Interface for Smart Walker Assisted Gait: AGoRA Walker*, in "Sensors", July 2019, vol. 19, n$^{\text{o}}$ 13, pp. 1-29 [*DOI :* 10.3390/S19132897], https://hal.inria.fr/hal-02182511

[25] J. VALENTE, J. J. ROLDÁN, M. GARZÓN, A. BARRIENTOS. *Towards Airborne Thermography via Low-Cost Thermopile Infrared Sensors*, in "Drones", March 2019, vol. 3, n$^{\text{o}}$ 1, pp. 1-11 [*DOI :* 10.3390/DRONES3010030], https://hal.inria.fr/hal-02086238

Invited Conferences

[26] C. LAUGIER. *A journey in the history of Automated Driving*, in "IROS 2019 - IEEE/RSJ International Conference on Intelligent Robots and Systems", Macau, China, IEEE, November 2019, pp. 1-27, Invited Pionneer's talk at IEEE/RSJ IROS 2019, https://hal.inria.fr/hal-02428196

[27] C. LAUGIER. *Embedded Sensor Fusion and Perception for Autonomous Vehicle*, in "IS Auto Europe 2019 - Image Sensors Automotive Conference", Berlin, Germany, April 2019, pp. 1-30, https://hal.inria.fr/hal-02434279

[28] C. LAUGIER. *Impact of AI on Autonomous Driving*, in "WRC 2019 - WRC 2019- IEEE World Robot Conference", Beijing, China, IEEE, August 2019, pp. 1-27, https://hal.inria.fr/hal-02429111

[29] C. LAUGIER. *Mixing Bayesian and Artificial Intelligence approaches for Autonomous Driving*, in "Tech M&A 2019 - Minalogic Technical Conference", Grenoble, France, May 2019, https://hal.inria.fr/hal-02434275

[30] C. LAUGIER. *Situation Awareness & Decision-making for Autonomous Driving*, in "IROS 2019 - IEEE/RSJ International Conference on Intelligent Robots and Systems", Macau, China, IEEE, November 2019, pp. 1-25, https://hal.inria.fr/hal-02429023

International Conferences with Proceedings

[31] M. BARBIER, A. RENZAGLIA, J. QUILBEUF, L. RUMMELHARD, A. PAIGWAR, C. LAUGIER, A. LEGAY, J. IBAÑEZ-GUZMÁN, O. SIMONIN. *Validation of Perception and Decision-Making Systems for Autonomous Driving via Statistical Model Checking*, in "IV 2019 - 30th IEEE Intelligent Vehicles Symposium", Paris, France, IEEE, June 2019, pp. 252-259 [*DOI :* 10.1109/IVS.2019.8813793], https://hal.inria.fr/hal-02127889

[32] R. BRESSON, J. SARAYDARYAN, J. DUGDALE, A. SPALANZANI. *Socially Compliant Navigation in Dense Crowds*, in "IV 2019 - 30th IEEE Intelligent Vehicles Symposium", Paris, France, IEEE, June 2019, pp. 64-69 [*DOI :* 10.1109/IVS.2019.8814288], https://hal.inria.fr/hal-02096006

[33] S. D'ALU, O. IOVA, O. SIMONIN, H. RIVANO. *Demo: In-flight Localisation of Micro-UAVs using Ultra-Wide Band*, in "EWSN 2020 - International Conference on Embedded Wireless Systems and Networks", Lyon, France, ACM, February 2020, https://hal.archives-ouvertes.fr/hal-02421783

[34] Q. DEBARD, J. STEEVE DIBANGOYE, S. CANU, C. WOLF. *Learning 3D Navigation Protocols on Touch Interfaces with Cooperative Multi-Agent Reinforcement Learning*, in "ECML PKDD 2019 - European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases", Würzburg, Germany, ECML PKDD 2019 - European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases, 2019, pp. 1-16, https://hal.archives-ouvertes.fr/hal-02302554

[35] N. DESHPANDE, A. SPALANZANI. *Deep Reinforcement Learning based Vehicle Navigation amongst pedestrians using a Grid-based state representation*, in "ITSC 2019 - IEEE Intelligent Transportation Systems Conference", Auckland, New Zealand, IEEE, October 2019, pp. 2081-2086 [*DOI :* 10.1109/ITSC.2019.8917299], https://hal.inria.fr/hal-02409042

[36] R. GRÜNBLATT, I. GUÉRIN-LASSOUS, O. SIMONIN. *Simulation and Performance Evaluation of the Intel Rate Adaptation Algorithm*, in "MSWiM 2019 - 22nd ACM International Conference on Modeling, Analysis

and Simulation of Wireless and Mobile Systems", Miami Beach, United States, ACM, November 2019, pp. 27-34 [*DOI :* 10.1145/3345768.3355921], https://hal.inria.fr/hal-02282508

[37] V.-S. IONESCU, Z. ONET-MARIAN, M.-G. BADITA, G. CZIBULA, M.-I. POPESCU, J. S. DIBANGOYE, O. SIMONIN. *DynFloR: A Flow Approach for Data Delivery Optimization in Multi-Robot Network Patrolling*, in "KES 2019 - 23rd International Conference on Knowledge-Based and Intelligent Information & Engineering Systems", Budapest, Hungary, September 2019, https://hal.archives-ouvertes.fr/hal-02386692

[38] P. LEDENT, A. PAIGWAR, A. RENZAGLIA, R. MATEESCU, C. LAUGIER. *Formal Validation of Probabilistic Collision Risk Estimation for Autonomous Driving*, in "CIS-RAM 2019 - 9th IEEE International Conference on Cybernetics and Intelligent Systems (CIS) Robotics, Automation and Mechatronics (RAM)", Bangkok, Thailand, IEEE, November 2019, pp. 1-6, https://hal.inria.fr/hal-02355551

[39] A. PAIGWAR, Ö. ERKENT, C. WOLF, C. LAUGIER. *Attentional PointNet for 3D-Object Detection in Point Clouds*, in "CVPR 2019 - Workshop on Autonomous driving", Long Beach, California, United States, June 2019, pp. 1-10, https://hal.inria.fr/hal-02156555

[40] M. PRÉDHUMEAU, J. DUGDALE, A. SPALANZANI. *Adapting the Social Force Model for Low Density Crowds in Open Environments*, in "15th Social Simulation Conference", Mainz, Germany, September 2019, https://hal.archives-ouvertes.fr/hal-02194735

[41] B. RENAULT, J. SARAYDARYAN, O. SIMONIN. *Towards S-NAMO: Socially-aware Navigation Among Movable Obstacles*, in "RoboCup 2019 - 23rd Annual RoboCup International Symposium", Sydney, Australia, S. CHALUP, T. NIEMUELLER, J. SUTHAKORN, M.-A. WILLIAMS (editors), RoboCup 2019: Robot World Cup XXIII, Springer, July 2019, pp. 241-254, https://arxiv.org/abs/1909.10809 [*DOI :* 10.1007/978-3-030-35699-6_19], https://hal.archives-ouvertes.fr/hal-02293242

[42] A. RENZAGLIA, J. S. DIBANGOYE, V. LE DOZE, O. SIMONIN. *Combining Stochastic Optimization and Frontiers for Aerial Multi-Robot Exploration of 3D Terrains*, in "IROS 2019 - IEEE/RSJ International Conference on Intelligent Robots and Systems", Macau, China, November 2019, https://hal.inria.fr/hal-02164806

[43] *Best Paper*
J. SARAYDARYAN, R. LEBER, F. JUMEL. *People management framework using a 2D camera for human-robot social interactions*, in "RoboCup 2019 - 23rd Annual RoboCup International Symposium", Sydney, Australia, Robocup 2019: Robot World Cup XXIII, July 2019, pp. 1-13, https://hal.archives-ouvertes.fr/hal-02318916.

[44] D. SIERRA GONZÁLEZ, M. GARZÓN, J. S. DIBANGOYE, C. LAUGIER. *Human-Like Decision-Making for Automated Driving in Highways*, in "ITSC 2019 - 22nd IEEE International Conference on Intelligent Transportation Systems", Auckland, New Zealand, October 2019, pp. 1-8, https://hal.inria.fr/hal-02188235

[45] C. YANG, A. RENZAGLIA, A. PAIGWAR, C. LAUGIER, D. WANG. *Driving Behavior Assessment and Anomaly Detection for Intelligent Vehicles*, in "CIS-RAM 2019 - 9th IEEE International Conference on Cybernetics and Intelligent Systems (CIS) Robotics, Automation and Mechatronics (RAM)", Bangkok, Thailand, November 2019, pp. 1-6, https://hal.inria.fr/hal-02355809

National Conferences with Proceedings

[46] R. GRÜNBLATT, I. GUÉRIN-LASSOUS, O. SIMONIN. *Study of the Intel WiFi Rate Adaptation Algorithm*, in "CoRes 2019 - Rencontres Francophones sur la Conception de Protocoles, l'Évaluation de Performance et l'Expérimentation des Réseaux de Communication", Saint-Laurent-de-la-Cabrerisse, France, June 2019, pp. 1-4, https://hal.inria.fr/hal-02126333

[47] A. RENZAGLIA, J. S. DIBANGOYE, V. LE DOZE, O. SIMONIN. *Combiner Optimisation Stochastique et Frontières pour l'Exploration 3D avec un Flotte de Drones*, in "JFSMA 2019 - 27èmes Journées Francophones sur les Systèmes Multi-Agents (JFSMA)", Toulouse, France, July 2019, pp. 1-9, https://hal.inria.fr/hal-02160346

Conferences without Proceedings

[48] M. GARZÓN, A. SPALANZANI. *Game theoretic decision making for autonomous vehicles' merge manoeuvre in high traffic scenarios*, in "ITSC 2019 - IEEE Intelligent Transportation Systems Conference", Auckland, New Zealand, IEEE, October 2019, pp. 3448-3453 [*DOI :* 10.1109/ITSC.2019.8917314], https://hal.archives-ouvertes.fr/hal-02388757

Scientific Books (or Scientific Book chapters)

[49] M. BARBIER, J. IBAÑEZ-GUZMÁN, C. LAUGIER, O. SIMONIN. *Validation Framework Applied to the Decision-Making Process for an Autonomous Vehicle Crossing Road Intersections*, in "Validation and Verification of Automated Systems", Springer International Publishing, November 2020, pp. 179-205 [*DOI :* 10.1007/978-3-030-14628-3_15], https://hal.inria.fr/hal-02424651

Research Reports

[50] R. ASGHAR, M. GARZÓN, J. LUSSEREAU, C. LAUGIER. *Map Relative Localization Based on Visual and Topological Map Matching*, Inria Chroma, September 2019, https://hal.inria.fr/hal-02412837

[51] L. BRIÑÓN-ARRANZ, A. RENZAGLIA, L. SCHENATO. *Technical report on: Multi-Robot Symmetric Formations for Gradient and Hessian Estimation with Application to Source Seeking*, Inria Grenoble Rhône-Alpes, Université de Grenoble, January 2019, pp. 1-8, https://hal.inria.fr/hal-01989573

[52] M. A. DIAZ ZAPATA. *Contribution to Panoptic Segmentation*, Inria ; Universidad Autónoma de Occidente, September 2019, n° RT-0506, https://hal.inria.fr/hal-02300774

Other Publications

[53] Q. DEBARD, J. STEEVE DIBANGOYE, S. CANU, C. WOLF. *Learning 3D Navigation Protocols on Touch Interfaces with Cooperative Multi-Agent Reinforcement Learning*, October 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02302526

[54] A. PAIGWAR, Ö. ERKENT, C. WOLF, C. LAUGIER. *Attentional PointNet for 3D-Object Detection in Point Clouds*, June 2019, 1 p. , CVPR 2019 - Workshop on Autonomous Driving, Poster, https://hal.inria.fr/hal-02160868

[55] O. SIMONIN. *Decision Making in (multi) Robot Systems*, January 2019, pp. 1-50, Lecture, https://hal.inria.fr/cel-02130231

References in notes

[56] *Global status report on road safety 2018*, in "World Health Organization", 2018

[57] G. AOUDE, B. LUDERS, K. LEE, D. LEVINE, J. HOW. *Threat assessment design for driver assistance system at intersections*, in "Intelligent Transportation Systems (ITSC), 2010 13th International IEEE Conference on", sept. 2010, pp. 1855 -1862

[58] E. BEECHING, C. WOLF, J. DIBANGOYE, O. SIMONIN. *Deep Reinforcement Learning on a Budget: 3D Control and Reasoning Without a Supercomputer*, in "Arxiv pre-print 1904.01806", 2019

[59] R. E. BELLMAN. *Dynamic Programming*, Dover Publications, Incorporated, 1957

[60] F. A. W. BELO, P. SALARIS, A. BICCHI. *3 Known Landmarks are Enough for Solving Planar Bearing SLAM and Fully Reconstruct Unknown Inputs*, in "International Conference on Intelligent Robots and Systems (IROS)", IEEE, December 2010

[61] M. BENNEWITZ, W. BURGARD, G. CIELNIAK, S. THRUN. *Learning motion patterns of people for compliant robot motion*, in "Int. J. of Robot. Res.", 2005, vol. 24, pp. 31–48

[62] G. BONO, J. S. DIBANGOYE, L. MATIGNON, F. PEREYRON, O. SIMONIN. *Classification des problèmes stochastiques et dynamiques de collectes et de livraisons par des véhicules intelligents*, in "Journées Francophones sur la Planification, la Décision et l'Apprentissage pour la conduite de systèmes (JFPDA 2017)", Caen, France, July 2017, https://hal.archives-ouvertes.fr/hal-01576351

[63] S.-G. CHITIC, J. PONGE, O. SIMONIN. *SDfR -Service discovery for multi-robot systems*, in "ICAART 2016 The 8th International Conference on Agents and Artificial Intelligence", Rome, Italy, February 2016, https://hal.archives-ouvertes.fr/hal-01286895

[64] J. CIVERA, D. GALVEZ-LOPEZ, L. RIAZUELO, J. D. TARDÓS, J. M. M. MONTIEL. *Towards semantic SLAM using a monocular camera*, in "IROS", 2011

[65] C. COUÉ, C. PRADALIER, C. LAUGIER, T. FRAICHARD, P. BESSIÈRE. *Bayesian Occupancy Filtering for Multi-Target Tracking: an Automotive Application*, in "Int. Journal of Robotics Research", January 2006, vol. 25, n° 1, pp. 19–30

[66] S. DAS, P. N. SUGANTHAN. *Differential evolution: a survey of the state-of-the-art*, in "IEEE transactions on evolutionary computation", 2011, vol. 15, n° 1, pp. 4–31

[67] J. S. DIBANGOYE, C. AMATO, O. BUFFET, F. CHARPILLET. *Exploiting Separability in Multiagent Planning with Continuous-State MDPs (Extended Abstract)*, in "24th International Joint Conference on Artificial Intelligence (IJCAI)", 2015, pp. 4254–4260

[68] J. S. DIBANGOYE, C. AMATO, O. BUFFET, F. CHARPILLET. *Optimally Solving Dec-POMDPs as Continuous-State MDPs*, in "Journal of Artificial Intelligence Research", February 2016, vol. 55, pp. 443-497 [*DOI :* 10.1613/JAIR.4623], https://hal.inria.fr/hal-01279444

[69] G. FERRER, A. SANFELIU. *Bayesian Human Motion Intentionality Prediction in urban environments*, in "Pattern Recognition Letters", 2014, vol. 44, n° 0, pp. 134 - 140, Pattern Recognition and Crowd

Analysis [*DOI* : 10.1016/J.PATREC.2013.08.013], http://www.sciencedirect.com/science/article/pii/S0167865513003176

[70] C. FORSTER, M. PIZZOLI, D. SCARAMUZZA. *SVO: Fast Semi-Direct Monocular Visual Odometry*, in "ICRA", 2014

[71] C. FULGENZI, C. TAY, A. SPALANZANI, C. LAUGIER. *Probabilistic navigation in dynamic environment using Rapidly-exploring Random Trees and Gaussian Processes*, in "IEEE/RSJ 2008 International Conference on Intelligent RObots and Systems", France Nice, 2008, http://hal.inria.fr/inria-00332595/en/

[72] A. GEIGER, P. LENZ, R. URTASUN. *Are we ready for Autonomous Driving? The KITTI Vision Benchmark Suite*, in "Conference on Computer Vision and Pattern Recognition (CVPR)", 2012

[73] K. HE, G. GKIOXARI, P. DOLLÁR, R. GIRSHICK. *Mask r-cnn*, in "Proceedings of the IEEE international conference on computer vision", 2017, pp. 2961–2969

[74] J. HESCH, D. KOTTAS, S. BOWMAN, S. ROUMELIOTIS. *Consistency analysis and improvement of vision-aided inertial navigation*, in "Trans. on Rob.", 2014, vol. 30, n^{o} 1, pp. 158–176

[75] A. KIRILLOV, K. HE, R. GIRSHICK, C. ROTHER, P. DOLLÁR. *Panoptic segmentation*, in "Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition", 2019, pp. 9404–9413

[76] S. LEFÈVRE, R. BAJCSY, C. LAUGIER. *Probabilistic Decision Making for Collision Avoidance Systems: Postponing Decisions*, in "IEEE/RSJ International Conference on Intelligent Robots and Systems", Tokyo, Japan, 2013, https://hal.inria.fr/hal-00880440

[77] S. LEUTENEGGER, P. FURGALE, V. RABAUD, M. CHLI, K. KONOLIGE, R. SIEGWART. *Keyframe-based visual-inertial odometry using nonlinear optimization*, in "Int. J. of Rob. Res.", 2014

[78] A. MARTINELLI. *State Estimation based on the Concept of Continuous Symmetry and Observability Analysis: The Case of Calibration*, in "IEEE Transactions on Robotics", May 2011, http://hal.inria.fr/hal-00578795/en

[79] A. MARTINELLI. *Vision and IMU Data Fusion: Closed-Form Solutions for Attitude, Speed, Absolute Scale and Bias Determination*, in "Transaction on Robotics", 2012, vol. 28, n^{o} 1

[80] A. MARTINELLI. *Observabilty Properties and Deterministic Algorithms in Visual-Inertial Structure from Motion*, in "Foundations and Trends in Robotics (FnTROB)", December 2013, pp. 1–75 [*DOI :* 10.1088/1742-5468/2014/03/P03003], https://hal.inria.fr/hal-01096948

[81] A. MARTINELLI. *Closed-form solution of visual-inertial structure from motion*, in "International Journal of Computer Vision", January 2014, vol. 106, n^{o} 2, pp. 138–152

[82] L. MATIGNON, O. SIMONIN. *Multi-Robot Simultaneous Coverage and Mapping of Complex Scene - Comparison of Different Strategies*, in "AAMAS 2018 - 17th International Conference on Autonomous Agents and Multiagent Systems - Robotics Track", Stockholm, Sweden, ACM, July 2018, pp. 559-567

[83] D. NEVEN, B. D. BRABANDERE, S. GEORGOULIS, M. PROESMANS, L. V. GOOL. *Towards End-to-End Lane Detection: an Instance Segmentation Approach*, in "CoRR", 2018, vol. abs/1802.05591, http://arxiv.org/abs/1802.05591

[84] A. NÈGRE, L. RUMMELHARD, C. LAUGIER. *Hybrid Sampling Bayesian Occupancy Filter*, in "IEEE Intelligent Vehicles Symposium (IV)", Dearborn, United States, June 2014, https://hal.inria.fr/hal-01011703

[85] A. PANDEY, R. ALAMI. *A framework towards a socially aware Mobile Robot motion in Human-Centered dynamic environment*, in "IEEE/RSJ International Conference on Intelligent Robots and Systems", oct. 2010, pp. 5855 -5860

[86] M.-I. POPESCU, H. RIVANO, O. SIMONIN. *Multi-robot Patrolling in Wireless Sensor Networks using Bounded Cycle Coverage*, in "ICTAI 2016 28th International Conference on Tools with Artificial Intelligence", San Jose, United States, IEEE, November 2016, https://hal.archives-ouvertes.fr/hal-01357866

[87] C. R. QI, H. SU, K. MO, L. J. GUIBAS. *Pointnet: Deep learning on point sets for 3d classification and segmentation*, in "Proc. Computer Vision and Pattern Recognition (CVPR), IEEE", 2017, vol. 1, n^{o} 2, 4 p.

[88] A. RENZAGLIA, J. DIBANGOYE, V. LE DOZE, O. SIMONIN. *Multi-UAV Visual Coverage of Partially Known 3D Surfaces: Voronoi-based Initialization to Improve Local Optimizers*, in "arXiv preprint arXiv:1901.10272", 2019

[89] L. RUMMELHARD, A. NÈGRE, C. LAUGIER. *Conditional Monte Carlo Dense Occupancy Tracker*, in "18th IEEE International Conference on Intelligent Transportation Systems", Las Palmas, Spain, September 2015, https://hal.inria.fr/hal-01205298

[90] M. SANDLER, A. HOWARD, M. ZHU, A. ZHMOGINOV, L. C. CHEN. *MobileNetV2: Inverted Residuals and Linear Bottlenecks*, in "CVPR", 2018, pp. 4510–4520

[91] D. SIERRA GONZÁLEZ, V. ROMERO-CANO, J. STEEVE DIBANGOYE, C. LAUGIER. *Interaction-Aware Driver Maneuver Inference in Highways Using Realistic Driver Models*, in "Proceedings of the 2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC 2017)", Yokohama, Japan, October 2017, https://hal.inria.fr/hal-01589493

[92] O. SIMONIN, F. CHARPILLET, E. THIERRY. *Revisiting wavefront construction with collective agents: an approach to foraging*, in "Swarm Intelligence", June 2014, vol. 8, n^{o} 2, pp. 113-138 [*DOI :* 10.1007/s11721-014-0093-3], https://hal.inria.fr/hal-00974068

[93] A. SPALANZANI, J. RIOS-MARTINEZ, C. LAUGIER, S. LEE. *Risk Based Navigation Decisions*, in "Handbook of Intelligent Vehicles", A. ESKANDARIAN (editor), Springer Verlag, February 2012, vol. 1, http://hal.inria.fr/hal-00743336

[94] K. TATENO, F. TOMBARI, I. LAINA, N. NAVAB. *CNN-SLAM: Real-time dense monocular SLAM with learned depth prediction*, in "CVPR", 2017

[95] M. TEICHMANN, M. WEBER, J. M. ZÖLLNER, R. CIPOLLA, R. URTASUN. *MultiNet: Real-time Joint Semantic Reasoning for Autonomous Driving*, in "CoRR", 2016, vol. abs/1612.07695, http://arxiv.org/abs/1612.07695

[96] S. THRUN, W. BURGARD, D. FOX. *Probabilistic Robotics*, The MIT Press, September 2005, 1 p.

[97] M. TLIG, O. BUFFET, O. SIMONIN. *Stop-Free Strategies for Traffic Networks: Decentralized On-line Optimization*, in "ECAI 2014 - 21st European Conference on Artificial Intelligence, 18-22 August 2014, Prague, Czech Republic - Including Prestigious Applications of Intelligent Systems (PAIS 2014)", 2014, pp. 1191–1196, http://dx.doi.org/10.3233/978-1-61499-419-0-1191

[98] P. VASISHTA, D. VAUFREYDAZ, A. SPALANZANI. *Natural Vision Based Method for Predicting Pedestrian Behaviour in Urban Environments*, in "IEEE 20th International Conference on Intelligent Transportation Systems", Yokohama, Japan, October 2017, https://hal.inria.fr/hal-01561029

[99] P. VASISHTA, D. VAUFREYDAZ, A. SPALANZANI. *Building Prior Knowledge: A Markov Based Pedestrian Prediction Model Using Urban Environmental Data*, in "ICARCV 2018 - 15th International Conference on Control, Automation, Robotics and Vision", Singapore, Singapore, November 2018, pp. 1-12

[100] D. VASQUEZ, Y. YU, S. KUMAR, C. LAUGIER. *An open framework for human-like autonomous driving using Inverse Reinforcement Learning*, in "IEEE Vehicle Power and Propulsion Conference", 2014

[101] T. VIDAL, T. G. CRAINIC, M. GENDREAU, C. PRINS. *A Hybrid Genetic Algorithm with Adaptive Diversity Management for a Large Class of Vehicle Routing Problems with Time-windows*, in "Comput. Oper. Res.", January 2013, vol. 40, n^{o} 1, pp. 475–489

[102] J. VON NEUMANN, O. MORGENSTERN. *Theory of games and economic behavior*, Princeton University Press, 2007

[103] J. VON NEUMANN, O. MORGENSTERN. *Theory of Games and Economic Behavior*, Princeton University Press, 1944