IN PARTNERSHIP WITH:
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Activity Report 2017

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 Rhone-Alpes between Grenoble and Lyon. 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 [1] Lyon [2] working in the robotic group led by Prof. Olivier Simonin in CITI Lab. [3] (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) and Dizan Vasquez (Inria starting researcher SRP). On December 1st, 2015, Anne Spalanzani (Asso. Prof. Univ. Grenoble, habilite) joined the team (she was previously member of Prima and eMotion Inria project-teams). In January 2016, Dizan Vasquez left the team to join Apple.

[1] National Institute of Applied Sciences
[2] INSA Lyon is part of the University de Lyon
[3] Centre of Innovation in Telecommunications and Integration of Service, see http://www.citi-lab.fr/

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” [4] and “Multi-Robot Systems (MRS) [5]".

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 third challenge of the **Inria 2013-2017 Strategic Plan "Interacting with the real and digital worlds: interaction, uses and learning"**.

2.3. Research themes

To address previous 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 complementary advantages of two orthogonal approaches, Multi-Agent Sequential Decision Making (MA-SDM) and Swarm Intelligence (SI).

[4] 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

[5] IEEE RAS Multi-Robot Systems http://multirobotsystems.org/

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 on many projects in collaboration with automobile companies (including Renault, Toyota and Volvo) and startups.

3. Research Program

3.1. Introduction

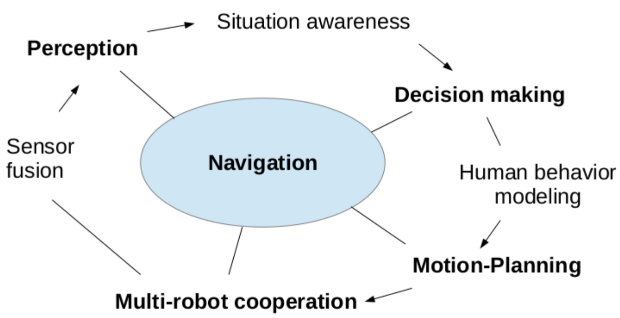

Figure 1. Research themes of the team and their relation

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 (large) 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 [6] (Prof Christoph Stiller lab and Prof Ruediger Dillmann lab), UC Berkeley, Vislab Parma (Prof. Alberto Broggi), and iCeiRA [7] 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 Sections 9.3 and 9.4.

3.2. Perception and Situation Awareness

Participants: Christian Laugier, Agostino Martinelli, Jilles S. Dibangoye, Anne Spalanzani, Olivier Simonin, Christian Wolf.

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 [8] 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**.

[6] Karlsruhe Institut fur Technologie
[7] International Center of Excellence in Intelligent Robotics and Automation Research.
[8] partially unknown and open

Figure 2. Illustrations of the HSBOF model and experiment with the Zoe car

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 [45] and further developed in the team [9]. 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-Perfect 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 *HSBOF* (Hybrid Sampling Bayesian Occupancy Filter) approach [71] or the *CMCDOT* (Conditional Monte Carlo Dense Occupancy Tracker) framework [76] which is still under development.

This work is currently mainly performed in the scope of the Perfect project (IRT Nanoelec), and more recently in cooperation with some Industrial companies (see section New Results for more details).

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 3 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.

3.2.2. Simulated based 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 [10] 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

[9] The Bayesian programming formalism developed in e-Motion, pioneered (together with the contemporary work of Thrun, Burgard and Fox [82]) a systematic effort to formalize robotics problems under Probability theory–an approach that is now pervasive in Robotics.

[10] Advance Driving Assistance System

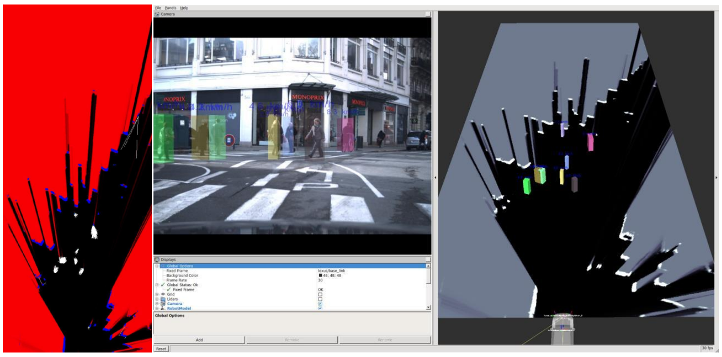

Figure 3. Illustration of the Bayesian Perception Paradigm: Filtered occupancy grids, enhanced with motion estimations (vectors) and object detection (colored boxes)

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 the Perfect 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.

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.

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 abovementioned SMC approach).

3.2.3. Simulated based validation

Context. Designing and implementing an efficient, reactive and safe embedded system for autonomous vehicles, is still a scientific and technological challenge. Such a system has to appropriately integrate interdependent functionalities such as Perception, Decision-making and Motion Control. More precisely, it is required to continuously combine (1) the output of our Bayesian Perception system (occupancy grid, motion fields, detected & tracked sub-objects, short-term prediction & collision risk assessment), (2) a Decision-making process providing safe goal-oriented navigation task (local motion planning and on-line static & dynamic obstacle avoidance maneuvers), and (3) a vehicle Control unit capable of executing in a reactive and safe way the current navigation task (nominal trajectory tracking, emergency maneuvers for avoiding imminent collisions).

This work is mainly performed in the scope of the Perfect project (IRT Nanoelec), of our cooperation with Ecole Centrale Nantes, and of several R&D projects with Renault (FUI Tornado and PhD Thesis). Our experimental platform Renault Zoé has been automated in 2017, by integrating a control unit having the capability of operating either in an *ADAS* [11] mode or in a fully autonomous mode.

Objectives. We started to work on this new research topic in 2017. The main objective is to design and develop a framework for safe and reactive navigation in a highly dynamic environment, by integrating our Bayesian Perception system with appropriates Decision-making and Motion Control components. Such a system has to be able to operate either in an *ADAS* mode (i.e. in interaction with a human driver), or in a fully autonomous mode. Two main questions have to be first addressed:

- How to generate and execute emergency maneuvers for avoiding an imminent collision detected and characterized by the Perception system (with the *CMCDOT* approach, the collision risk is specified in terms of probability, spatial localization and expected time-to-collision)? In the context of an *ADAS* system assisting a human driver, the system automatically triggers the braking and/or the steering controls for avoiding the collision (while the human driver is driving the vehicle).
- How to autonomously navigate towards a given goal in a dynamic and open environment, while avoiding any collision with stationary or dynamic obstacles detected by the embedded Perception system ? In this case, an on-line trajectory planner taking into account the dynamic characteristics of the vehicle, the environment map (if any) and the output of the Perception system has to be used. Appropriate control functions (e.g. predictive control paradigm?) have also to be used.

3.2.4. 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 [12] predictions on the likely future evolution of the observed scene, even if the sensing information is temporary incomplete or not available [71]. 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 Perfect project (IRT Nanoelec) and of several cooperative and PhD projects with Toyota and 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 [13] 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 [57] 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 shortcomings of rules-based reasoning approaches which often show good results, but which lead to a lack of scalability and long terms predictions.

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

3.2.5. 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 [62] (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 [65], which extends a heuristic solution derived by the team of Prof. Antonio Bicchi [41] with whom we collaborate (Centro Piaggio at the University of Pisa).

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 [38], [59], [50]. Recently, this sensor fusion problem has been successfully addressed by enforcing observability constraints [52], [53] and by using optimization-based approaches [58], [49], [61], [54], [70]. 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 [63] and [64]. 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 [14] 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

Participants: Olivier Simonin, Anne Spalanzani, Jilles S. Dibangoye, Christian Wolf, Laetitia Matignon, Fabrice Jumel, Jacques Saraydaryan, Christian Laugier.

In his reference book *Planning algorithms* [15] 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 (p. 320). Moreover, dynamic and uncertain environments, as human-populated ones, expand this complexity.

[14] Navigation autonome des drones aériens avec la fusion des données visuelles et inertielles, lead by A. Martinelli, Chroma.
[15] Steven M. LaValle, Planning Algorithms, Cambridge University Press, 2006.

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

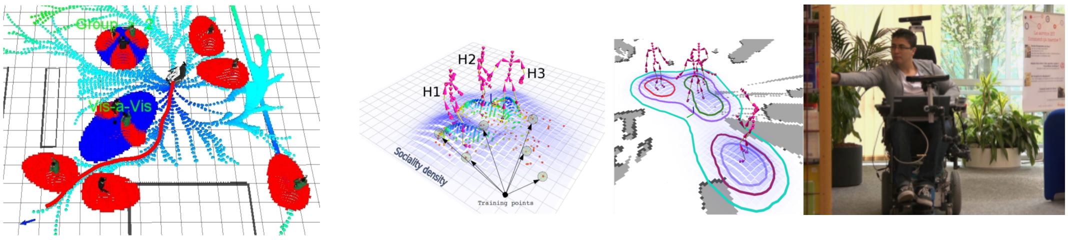

Figure 4. Illustrations of a. the Risk-RRT planning b. the human interaction space model c. experiment with the wheelchair.

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 [48], the MIT [37], the Autonomous Intelligent Systems lab in Freiburg [42], or the LAAS [72]. 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 [16] 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). This risk can be computed by methods proposed in the section 3.2.4. 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 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 [81] (see Figure 4.a for illustration). Now, we aim to 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 or in crowds).

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 4.b. We aim now to integrate semantic knowledge [17] and psycho-social theories of human behavior [18] [19] in the navigation framework we have developed for a few years (i.e. the Risk-based navigation algorithms [51], [81], [85]). These concepts were tested on our automated wheelchair (see figure 4.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, the ANR Hianic and the TENSIVE project.

[16] known environment without uncertainty
[17] B. Kuipers, The Spatial Semantic Hierarchy, Artificial Intelligence, Volume 119, Issues 1–2, May 2000, Pages 191-233
[18] 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.
[19] Hall, E. (1966). The hidden dimension. Doubleday Anchor Books.

Mapping human flows. We investigate the problem of modeling recurring human displacements to improve robots navigation in such dense populated environments. It has been shown that such recurring behaviors can be mapped from spatial-temporal observations, as in [83]. In this context we address the problem of mapping human flows from robot(s) perception. We started to propose counting-based mapping models [78] that contain motion probabilities in the grid cells (statistical learning) . Then such a grid can be exploited to define new cost-function exploited by path-planning algorithms (eg. A*) that take into account the probability to encounter humans in opposite direction. We also aim at demonstrating the efficiency of the approach with real robots evolving in dense human-populated environments.

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.

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 [20], resulting in computational overload. On their side, SI methods, which rely on local rules – generally bio-inspired – and relating to Self-Organized Systems [21], can scale up to multiple robots and provide robustness to disturbances, but with poor theoretical guarantees [22]. Swarm models can also answer to the need of designing tractable solutions [80], 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) [46]. 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 [84] the interest of such an approach for driverless vehicle traffic optimization. In 2016, we started a new PhD in collaboration with the VOLVO Group to deal with global-local optimization for goods distribution using a fleet of autonomous vehicles.

[20] Martin L. Puterman, Markov Decision Processes; Stuart Russell and Peter Norvig, Artificial Intelligence - A Modern Approach
[21] D. Floreano and C. Mattiussi, Bio-Inspired Artificial Intelligence - Theories, Methods, and Technologies, MIT Press, 2008.
[22] 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.

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 started to develop a methodology which relies on incrementally refining the environment representation while the robots perform their tasks, see [21].

Mastering the computational cost involved in cooperative decision-making relies also on building heuristics. We explore how exact (global) solutions can be decentralized in local computation allocated to group of robots or to each robot. We started to apply this methodology to dynamic problems such as the patrolling of moving persons (see [77]).

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 thousands of humans and 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.

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 constinuously changing and growing (see [73]).

Robot fleets should be able to adapt their behavior and organisation to communication limits and variation. It has been shown that wireless communication are very changing in time and space [60]. So we explore how robots can optimize their behaviors by perceiving and learning the quality of their communication in the environment (see our PHC "DRONEM" project).

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 [73] (wireless communication protocols) and with Dynamid team [44] (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.

[23] see for instance the first International Workshop on Cloud and Robotics, 2016.

Figure 5. 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).

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 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. 5 and Fig. 2), 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

[24] Advanced Driver Assistance Systems
[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

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 (Turtlebot fleet) or aerial ones (ANR VIMAD [28]), see Fig. 5. Since 2016, we develop solutions for 3D observation/exploration of complex scenes or environments with a fleet of UAVs (Inria ADT CORDES) or ground robots (COMODYS FIL project).

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 (see Figure 2 for illustration). We address the problem of assisting the user for joining a group of people and navigating in crowded environments, in cooperation with Inria Lagadic team (Rennes) and also in our recent ANR Hianic. Another emerging application to assist people is telepresence robot. In 2016 we started the TENSIVE project, funded by the Region, with the team of G. Bailly from GIPSA Lab (Grenoble) and with the Awabot and Hoomano companies (in Lyon). The project aims to improve the driving of such robots by providing a social and autonomous navigation (PhD of R. Cambuzat). Moreover, the project is supported by INSA-CITI Lab. through the acquisition of a Pepper robot (see Fig. 5).

5. Highlights of the Year

5.1. Highlights of the Year

- Chroma was created as EP Inria on December 1st, 2017.
- Christian Wolf, Associate Professor HDR at INSA Lyon and LIRIS Lab, obtained a full Inria delegation to join the Chroma team. He joined Chroma on September 2017.
- Laetitia Matignon, Associate Professor at Université de Lyon and LIRIS Lab, obtained a second-year half Inria delegation in Chroma.
- Vincent Le Doze joined the Chroma team in Lyon as Expert Inria Engineer, for 2 years, after we obtained the Inria ADT 'CORDES' project, focusing on UAVs control and planning (since Oct. 2017).
- We qualified to the international RobocupHome competition, after creating the 'LyonTech' team, which is composed of teacher-researchers from Chroma along with two engineers from LIRIS/CNRS lab. and CPE Lyon (we are the only french team qualified, the final is organized on June 2018 at Montreal).

6. New Software and Platforms

6.1. CUDA-HSBOF

FUNCTIONAL DESCRIPTION: Ce logiciel est une implémentation du filtre d'Occupation Bayésien à Echantillonnage Hybride (HSBOF) sur GPU. Cette version favorise l'intégration dans un système embarqué sur puce.

- Participants: Amaury Nègre, Christian Laugier and Lukas Rummelhard
- Contact: Christian Laugier

6.2. E.R.C.I.

Estimation du risque de collision aux intersections

- Participants: Christian Laugier, Javier Ibanez-Guzman and Stéphanie Lefevre
- Contact: Christian Laugier

[28] Navigation autonome des drones aériens avec la fusion des données visuelles et inertielles, lead by A. Martinelli, Chroma.
[29] Personnaly assisted Living

6.3. 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

6.4. kinetics

FUNCTIONAL DESCRIPTION: Software computing decision support strategies and decision-making

- Contact: Jilles Dibangoye

6.5. VI-SFM

FUNCTIONAL DESCRIPTION: Experimentary the closed Form Solution for usual-initial data fusion agains real and simulated fusion

- Authors: Agostino Martinelli and Jacques Kaiser
- Contact: Agostino Martinelli

6.6. Ground Elevation and Occupancy Grid Estilmator (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

6.7. 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, Amaury Nègre, Lukas Rummelhard, Lukas Rummelhard, Jean-Alix David and Christian Laugier
- Contact: Olivier Simonin

6.8. 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: Olivier Simonin

6.9. 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, Amaury Nègre, Lukas Rummelhard, Lukas Rummelhard and Jean-Alix David
- Contact: Olivier Simonin

6.10. CMCDOT-Tools

KEYWORD: Robotics
FUNCTIONAL DESCRIPTION: Tools for CMCDOT Software

- Authors: Amaury Nègre, Lukas Rummelhard, Lukas Rummelhard, Jean-Alix David, Mathias Perrollaz, Procopio Silveira-Stein, Jérôme Lussereau and Nicolas Vignard
- Contact: Olivier Simonin

6.11. DWA Planner on occupancy grid

Dynamic Window Approach Planner based on occupancy grid

KEYWORD: Navigation
FUNCTIONAL DESCRIPTION: This program considers : - a given target - an occupancy grid which represents the environment - the odometry of the vehicle With these data, it computes the commands for a safe navigation towards the target.

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

6.12. 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: Olivier Simonin

6.13. PedSim-ROS

FUNCTIONAL DESCRIPTION: Simulation of moving people and mobile robots that can detect agents around them. Integration of ROS mobile robots with the PedSim simulator.

- Contact: Jacques Saraydaryan

7. New Results

7.1. Bayesian Perception

Participants: Christian Laugier, Jean-Alix David, Thomas Genevois, Blanche Baudouin, Jerome Lussereau, Lukas Rummelhard [IRT Nanoelec], Tiana Rakotovao [CEA since October 2017], Nicolas Turro [SED], Jean-François Cuniberto [SED].

7.1.1. Conditional Monte Carlo Dense Occupancy Tracker (CMCDOT)

Participants: Christian Laugier, Jean-Alix David, Thomas Genevois, Blanche Baudouin, Jerome Lussereau, Lukas Rummelhard [IRT Nanoelec], Amaury Nègre [Gipsa Lab], Nicolas Turro [SED].

The research work on *Bayesian Perception* has been done as a continuation and an extension of our previous research activity and results on this approach [30]. This work exploits the initial *BOF* [31] paradigm (see section 3.2.1) and its recent new formulation and framework called *CMCDOT* [32] [76]. More details about these developments can be found in the Chroma Activity Report 2016.

[30] This research activity has been started in the scope of the former Inria team-project e-Motion and it is now conducted (since 2015) in the scope of the Inria Chroma team
[31] Bayesian Occupancy Filter
[32] Conditional Monte Carlo Dense Occupancy Tracker

The objective of the research work performed in 2017 on this topic, was to further refine the perception models and algorithms. Refinements have been made at three different levels:

- The occupancy grid generation process has been improved in order to appropriately process 2D and 3D lidars. In particular, the new *sensor model* for 3D lidar (called *GEOG-Estimator*), which was initially designed by the team in 2016, has been improved by adding a temporal filtering step for both obtaining a more accurate estimation of the elevation of the point cloud elements and a better occupancy grid generation with respect to the sensor calibration. This work has been published and patented in 2017 [24] [23]. The results are illustrated by Figure 6 and Figure 7.

  The *sensor model* for 2D lidar has also been modified in order to adapt it to the new paradigm introduce with GEOG-Estimator, with the objective to obtain a better fusion of the occupancy grids.

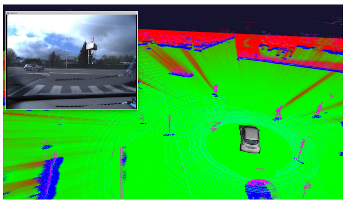

Figure 6. Example of Occupancy Grid generated using the classified point cloud and the Ground Estimator model.

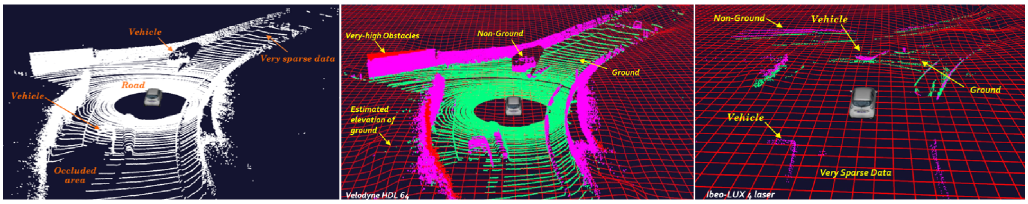

Figure 7. (a) Typical 3D point cloud generated by Velodyne LiDAR. (b) Point cloud segmentation between ground (green points) and non-ground (purple points), and estimated average elevation of the terrain (red grid). (c) Point Cloud Segmentation on 4-Ibeo Lux LiDAR data and estimated elevation of terrain.

- A new approach for fusing several occupancy grids has been developed to appropriately merge the outputs of different sensors (2D/3D lidars, stereo cameras, ...),
- The *CMCDOT* framework, which takes as input the merged occupancy grid, has been improved by adding new filtering equations whose objective is mainly to provide better results. In addition, a new output format has been added in order to make it easier the connection with the decision & control related components (see below).

All the above mentioned software modules are highly parallelizable. This is why a *GPU* implementation has been made and is continually optimized in order to obtain very efficient processing time and results. Now, the whole perception framework is able to run on low energy consumption embedded boards (Nvidia Jetson TX2). Thanks to this efficient embedded implementation, an industrial proof of concept on a commercial autonomous shuttle (from the EasyMile company) has successfully been done in a few weeks, Figure 8 illustrates.

These approach allow us to also develop a compact and portable demonstrator for conference or exhibitions, Figure 8(fourth picture) illustrates this technology.

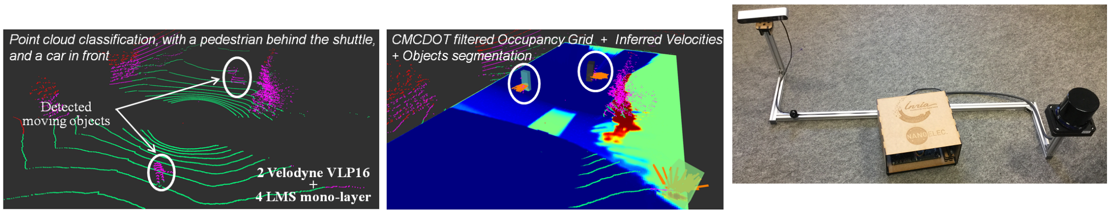

Figure 8. CMCDOT on a commercial autonomous shuttle EZ10 from EasyMile. a. classified point cloud b. detected dynamic objects and their velocities c. portable-demonstrator.

7.1.2. Simulation based validation

Participants: Thomas Genevois, Nicolas Turro [SED], Christian Laugier, Tiana Rakotovao [CEA since October 2017], Blanche Baudouin.

In 2017, we have started to address the concept of *simulation based validation* in the scope of the EU Enable-S3 project, with the objective of searching for novel approaches, methods, tools and experimental methodology for validating BOF-based algorithms. For that purpose, we have collaborated with the Inria Tamis team (Rennes) and with Renault for developing the simulation platform that is used in the test platform. The simulation of both the sensors and the driving environment are based on the Gazebo simulator. A simulation of the prototype car and its sensors has also been realized. In the simulator, the virtual Lidars generates the same format of data as the real ones, meaning that the same implementation of *CMCDOT* can handle both real data and simulated data. The test management component that generates random simulated scenarios has also been developed. Output of *CMCDOT* computed from the simulated scenarios are recorded by *ROS* and analyzed through the Statistical Model Checker developed by the Inria Tamis team.

Within the project Perfect, it has also been decided to use Gazebo to build our simulator. Gazebo is a simulation framework which gives many tools to simulate physics, sensors and actuators. Moreover, as Gazebo is fully compatible with *ROS*, it becomes easy for us to connect the simulator with our own perception and control tools (which are all using *ROS*).

We have developed a Gazebo model of the Inria Renault Zoe demonstrator, including physical properties (friction, inertia, sliding), sensors models (lidars and odometry) and real-like actuators (steering, acceleration and brake), Figure 9(first picture) illustrates. All parameters have been tuned to match with the actual vehicle and its equipment. In addition, several plug-in programs allow us to drive the virtual vehicle with the same commands as the actual vehicle; similarly, the simulated sensors provide data in the same format as the actual sensors. Therefore the simulated vehicle behaves much like the actual car, and any program running on the actual car can be directly used on the simulated model without any adaptation. This simulation is almost real time which is very convenient for development purposes.

Thanks to this simulated model, we have safely developed control and navigation software (emergency braking, path following and local navigation with obstacle avoidance). During this work, the simulation helped us to detect all issues and fully debug the programs before executing actual experiments. It showed that our model is well designed to behave like the real Zoe. Figure 9 illustrates the graphic output of the system.

Future work aims at improving these models for obtaining faster execution, better low level physical simulation (engine, brake, suspension), and new types of simulation sensors (cameras, IMU, radar, etc.). An industrial partner has already shown direct interest to our simulation model and asked for an adaptation to his own vehicle (no details can be given since this work is confidential).

7.1.3. Control and navigation

Participants: Thomas Genevois, Christian Laugier, Nicolas Turro [SED].

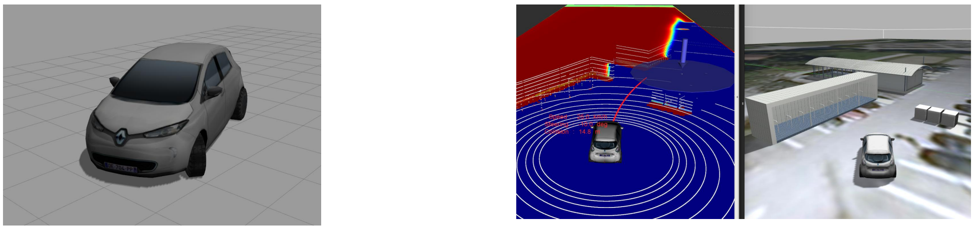

Figure 9. First picture: Display of the Zoe virtual model. Second picture: CMCDOT output computed by the simulator (using simulated sensors data). Third picture: Simulated scenario on Gazebo.

In January 2017, within a partnership with Ecole Centrale de Nantes, we realized a wired based control kit on the Renault Zoe experimental vehicle of the team.

We have first developed an *emergency braking system* to avoid collision during manual driving. This system triggers when the risk estimation provided by the *CMCDOT* reaches a threshold. Significant engineering work was necessary for being able to control the brake with the software, while letting the driver to drive normally. This has been successfully tested with both the simulator and the real vehicles in the PTL experimental platform of IRT-Nanoelec, Figure 10 illustrates.

We plan to improve this with different level of risk (long term, middle term and short term) which would trigger different actions (warning, progressive braking, emergency braking). To do so we will need to improve long term and middle term risk estimation reliability.

In a second step, we have started working on a *safe local navigation* component. For that purpose, we have implemented a Dynamic Window Approach (DWA) local planner based on occupancy grid. The DWA approach consists in computing online a set of feasible trajectories for the vehicle (in terms of vehicle control and no-collision in the near future). Then, a score is associated to each trajectory considering its collision risk, its heading with respect to the goal and its speed. Finally the trajectory with the best score is chosen and provided as a reference for the low level controller. The DWA technique affords a simple and flexible architecture and we took advantage of it to introduce the notion of time-to-collision within the score function. At the moment, the time-to-collision is computed from the occupancy grid provided by *CMCDOT*.

This approach has been successfully tested with in simulation and with the real vehicle on the PTL experimental platform of IRT-Nanoelec. It showed a good behaviour at slow speeds (<20km) on simple slalom and going through automated barriers (stops in front of the barriers and restarts when the barrier opens), Figure 10 illustrates.

Figure 10. Slalom-like obstacle course experiment in fully autonomous navigation mode

Current and future work aims at improving the approach at two levels: (1) developing a parallel implementation in Cuda on GPU for drastically improving the computation time, allowing in this way to compute in real-time several shapes of trajectories (i.e. for obtaining a better global motion) and to consider higher velocities and dynamic objects (i.e. anticipating the future motion of the moving objects); (2) improving the low level controller and the dynamic model of the vehicle (e.g. for computing the future positions of the vehicle from its odometry and the applied control commands), for obtaining a more precise control and better performances at higher speeds.

7.2. Situation Awareness

Participants: Christian Laugier, Olivier Simonin, Jilles Dibangoye, David Sierra-Gonzalez, Mathieu Barbier, Victor Romero-Cano, Ozgur Erkent, Christian Wolf.

7.2.1. Dense & Robust outdoor perception for autonomous vehicles

Participants: Christian Laugier, Victor Romero-Cano, Ozgur Erkent, Christian Wolf.

Robust perception plays a crucial role in the development of autonomous vehicles. While perception in normal and constant environmental conditions has reached a plateau, robustly perceiving changing and challenging environments has become an active research topic, particularly due to the safety concerns raised by the introduction of autonomous vehicles to public streets. Solving the robustness issue in road and urban perception applications is the first challenge. Then, it is also mandatory to develop an appropriate framework for extracting relevant semantic information. Our approach is to reason about vision-based data and the output of our grid-based multi-sensors perception approach (see previous section).

The work presented in this section has partly been done in 2016 and completed in 2017, in the scope of our collaboration with Toyota Motor Europe (TME). The main objective was to develop a framework for low-level multi-sensor data fusion in the pixel space. This framework is independent of the scene coverage of any of the sensors. It outputs a new image-like data representation where each pixel contains not only color but also other low level features such as depth and object IDs.

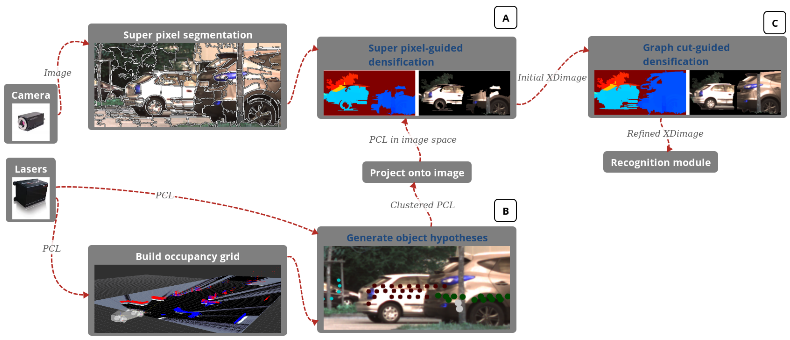

Figure 11. The XDvision framework.

The system depicted by Figure 11 addresses the problem of extending color images with sparse range data at the pixel level. To this end, we developed a framework for densifying sparse range data in the image space. Our framework provides a methodology for creating extended images independently of the density of the range sensor at hand. We adapted and combined two powerful segmentation techniques such as SLIC and Graph Cuts into a hierarchical methodology for depth densification. The experimental results show the advantages of our new low level data representation over using color only in an image classification task. Our framework achieves, from a camera and sparse/cheap range sensors, recognition results that are equivalent to those obtained from a camera and a dense/expensive 3D Velodyne. This work was patented [75] and published in [22].

Novel approach: Towards Semantic Occupancy Grids and robust *DATMO*[33]. Current and future work in the scope of our collaboration with TME, aims at constructing *Semantic Occupancy Grids* and at developing robust *DATMO*. The first objective is to develop occupancy grid mapping systems that exploit the precision of Lidar sensors and the dense and high level semantic information that can be obtained from camera sensors, in particular semantic segmentation systems. We are currently developing technologies that allow extending 2D occupancy grids with semantic and appearance information provided by semantic segmentations systems (**deep learning based**). These technologies allow us to probabilistically fuse occupancy maps and projected 2D segmentation maps both spatially and temporally.

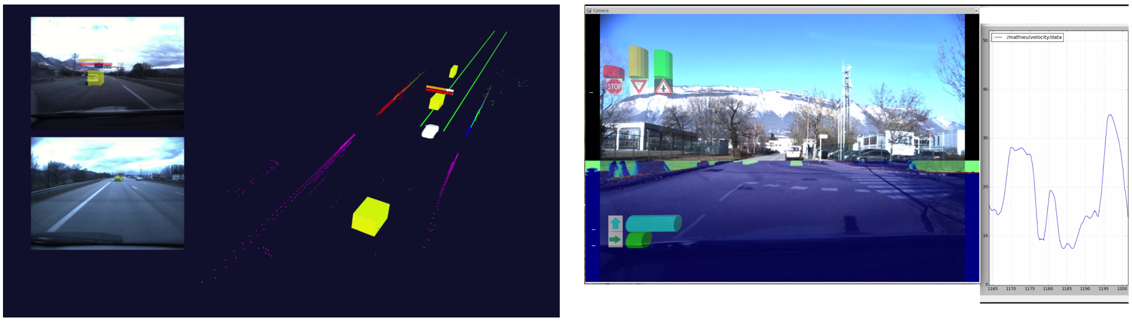

Figure 12.

a) D. Sierra-Gonzalez PhD. : In this highway traffic scene a driver cuts in front of the ego-vehicle. The red bar above the target shows the estimated marginal probability associated to the lane change maneuver. Lane change maneuvers are in most cases identified before the target touches the lane markings.
b) M. Barbier PhD. : Bottom left shows the most likely direction the driver intend to follow. The top left corner shows the probability over the possible longitudinal intention(stop, yield, pass) for the subject vehicle.

7.2.2. Towards Human-Like Motion Prediction and Decision-Making in Highway Scenarios

Participants: David Sierra-Gonzalez, Christian Laugier, Jilles Dibangoye, Victor Romero-Cano.

The objective of this project is to develop a collision risk estimation system capable of reliably finding the risk of collision associated to the different feasible trajectories of an autonomous or semi-autonomous vehicle. This research work is done in the scope of the Inria-Toyota long-term cooperation and of the PhD thesis work of David Sierra González. The practical output expected for the project is an Advanced Driver Assistance System (ADAS) for the Inria-TME Lexus experimental platform capable of suggesting to the driver in real-time the safest maneuver to perform while driving in the highway.

The research work done in the scope of this project in 2017 has focused on improving the state-of-the-art on short-term prediction of driver behavior in highways. The key idea is to model the behavior of highway drivers from demonstrated highway driving data using Inverse Reinforcement Learning and to exploit the resulting models for prediction. This has led to significant theoretical and experimental results on driver maneuver estimation [25], [26]. The proposed maneuver estimation framework has been validated with real-world highway data collected with an experimental vehicle (see Fig. 12.a). The results show that the system is characterized by short detection times and low false positive rates. This opens the door to the application of this work as part of a collision warning system. In 2017, this work has derived on an additional Inria-TME joint patent [79]. Current efforts are directed towards exploiting the uncertain predictions for decision-making.

[33] Detection and Tracking of Mobile Objects

The PhD thesis of David Sierra-Gonzalez will be defended in June 2018.

7.2.3. Decision-making for safe road intersection crossing

Participants: Mathieu Barbier, Christian Laugier, Olivier Simonin.

In continuation of the work done in 2016 about the functional space representation [39], we proposed a framework to observe the intention of intruder vehicle approaching an intersection. Random forest classifiers are used in conjunction with our functional discretization to analyze the trajectories of cars approaching an intersection. However each intersection can be different and the approach would scale poorly.

To address this problem, a hybrid data set was constructed. It is built in a simulated environment and completed with real data after a car drove multiple times across the intersection. We compared our approach against other classifiers and space discretization. In addition, we demonstrated the impact and the usefulness of the mixture between simulated and real data. An improvement of 30% accuracy is obtained with the hybrid data set, and 5% using our functional discretization with respect to baseline approach. It was also been implemented in our experimental platform as shown in see Fig. 12.b. This work has been published at IEEE IV 2017 [15].
The PhD thesis of Mathieu Barbier will be defended in June 2018.

The ongoing work use the bayesian network of [56] and extend it to a Partially observable decision process (POMDP). The Observation model uses the performances of the classification described previously to take into account the uncertainty over the intention [34]. The performances of this decision making system is investigated in the scope of the ENABLES-S3 project. With the use of simulation tools, multiple configurations and scenarios are tested. For each test, a set of "Key performances indicator (KPY)" is computed and used to judge the system. Such validation system has yet to be investigated and represent a major interest for both industry and research.

7.3. Robust state estimation (Sensor fusion)

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

7.3.1. Visual-inertial structure from motion

Participants: Agostino Martinelli, Alexander Oliva, Alessandro Renzaglia.

During this year we achieved the following two objectives:

1. (Theoretical) Extension of the closed form solution introduced in [64] to the cooperative case.
2. (Experimental) Improvement of one order of magnitude on the precision on the absolute scale determined by our closed form solution introduced in [64];

Regarding the first objective, we obtained a new theoretical and basic result in the framework of cooperative visual-inertial sensor fusion. Specifically, the case of two agents was investigated. First, the entire observable state was analytically derived. This state includes the relative position between the two aerial vehicles (which includes the absolute scale), the relative velocity and the three Euler angles that express the rotation between the two vehicle frames. Then, the basic equations that describe this system were analytically obtained. These results have been presented at the first international symposium on multi robot and multi agent systems [69]. Finally, we extended the closed form solution introduced in [64] to the cooperative case. Specifically, the observable state was expressed in closed form in terms of the measurements provided by monocular vision and inertial sensors, during a short time interval. We believe that this is a fundamental theoretical result, since it allows us from one side to automatically retrieve the absolute scale in closed form (and consequently without prior knowledge) even without observing external point features in the environment and, on the other side, to carry out a theoretical investigation that will allow us to detect all the system singularities. Extensive simulations and real experiments clearly show that the proposed solution is successful.

[34] This work will be the subject of a paper to be submitted to IEEE IV 2018

Regarding the second objective, our former experimental implementation provided a precision on the absolute scale in the range 10%-20% (all the details about the experimental setup are available in [55]). These former results were obtained in collaboration with the Robotics and Perception Group at the university of Zurich, in the framework of the ANR-VIMAD project. Specifically, the experiments were carried out in Zurich. This year, by an extensive use of the platform KINOVIS available at Inria, we investigated the impact of several sources of systematic error (imperfect extrinsic camera calibration, time delay and imperfect time alignment between sensors, etc.). We used simple methods to remove these error sources and we achieved the precision on the absolute scale in the range 1%-5%.

7.3.2. Unknown Input Observability

Participant: Agostino Martinelli.

During this year I achieved the following two objectives:

1. (Theoretical) Extension of the analytic solution presented in [66] to the driftless multiple unknown inputs case.
2. (Theoretical) Application of the solution in [66] to several problems, in the framework of computer vision, neuroscience and robotics.

Regarding the former objective, I obtained the general analytic solution of the nonlinear unknown input observability problem. As for the observability rank condition, the analytic criterion in presence of unknown inputs is based on the computation of the observable codistribution by a recursive and convergent algorithm. The algorithm is unexpectedly simple and can be easily and automatically applied to nonlinear systems driven by both known and unknown inputs, independently of their complexity and type of nonlinearity. Very surprisingly, the complexity of the overall analytic criterion is comparable to the complexity of the standard method to check the state observability in the case without unknown inputs (i.e., the observability rank condition). Given any nonlinear system characterized by any type of nonlinearity, driven by both known and unknown inputs, the state observability is obtained automatically, i.e., by following a systematic procedure (e.g., by the usage of a very simple code that uses symbolic computation). This is a fundamental practical (and unexpected) advantage. On the other hand, the analytic derivations and all the proofs necessary to analytically derive the algorithm and its convergence properties and to prove their general validity are very complex and they are extensively based on an ingenious analogy with the theory of General Relativity. In practice, these derivations largely use Ricci calculus with tensors (in particular, I largely adopt the Einstein notation to achieve notational brevity). All the results are fully described in a book, which is supposed to be published during the next year. A first draft of the book is now available on ArXiv (arXiv:1704.03252).

Regarding the second objective, the solution that holds in the driftless case and in presence of a single unknown input ([66]) has been used to investigate several problems. These problems include:

1. The unicycle in presence of a single disturbance (which has been presented at the SIAM on Control and Application 2017, [68]).
2. Vehicle moving in 3D in presence of a disturbance (which has been presented at the IROS 2017, [67])

Finally, the visual and inertial sensor fusion problem, when some of the inputs are unknown, has been investigated both in 2D and in 3D. All the results are described in chapter 5 of the book available on ArXiv (arXiv:1704.03252).

7.4. Motion-planning in human-populated environment

We explore motion planning algorithms to allow robots/vehicles to navigate in human populated environment, and to predict human motions. Since 2016, our work focuses on two directions, which are prediction of pedestrian behaviors in urban environments and mapping of human flows. We also started to investigate the navigation of a telepresence robot in collaboration with the GIPSA Lab. These works are presented here after.

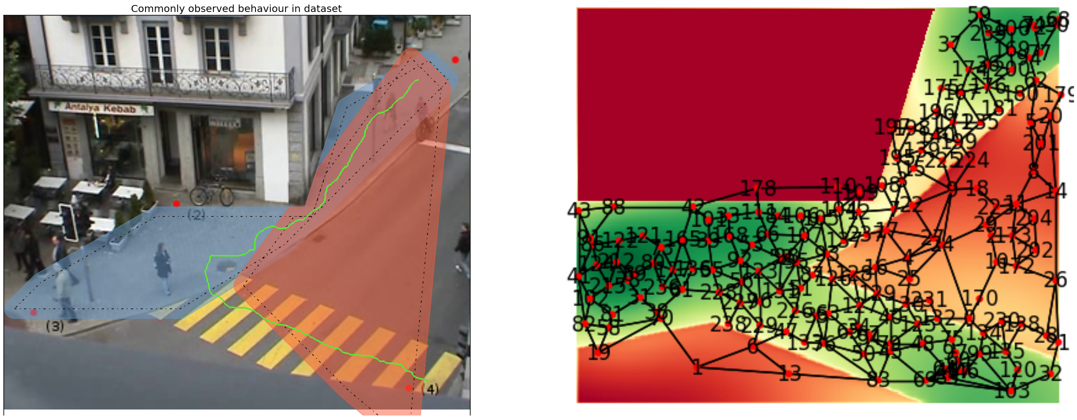

Figure 13. Illustration of (a) enclosure of areas predicted by the framework where pedestrian movements could occur. (b) Growing HMM for observed pedestrian trajectories at a randomly chosen time in the dataset

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 car or platoons (PhD work of P. Vasishta). In 2017 we 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 [30], [27]. Next year will be dedicated to combine this model with GHMM (Growing HMM) [86] to infer probable pedestrian paths in the scene to predict, for example, legal and illegal crossings, see. Fig. 13.

7.4.2. Learning task-based motion planning

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

Our goal is the automatic learning of robot navigation in human populated 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. recognize the current activities of all the actors in this environment) or which can be given in an encoded form as additional input. Addressing these problems requires competences in computer vision, machine learning, and robotics (navigation and paths planning).

We started this work in the end of 2017, following the arrival of C. Wolf, through combinations of reinforcement learning and deep learning. The underlying scientific challenge here is to automatic learn representations which allow the agent to solve multiple sub problems require 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, 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.

7.4.3. Modeling human-flows from robot(s) perception

Participants: Jacques Saraydaryan, Fabrice Jumel, Olivier Simonin.

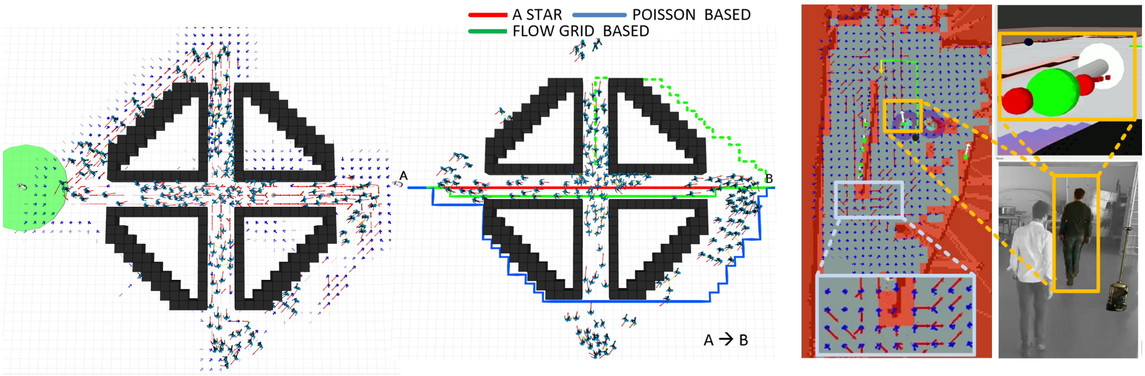

Figure 14. (a) Flow-grid mapping in a cross-corridor where 200 moving pedestrians turns (b) A path-planning computed with different cost functions (c) implementation and results with a real robot and environment*

In order to deal with robot navigation in dense human populated environments, eg. in flows of humans, we investigate the problem of mapping these flows. The challenge is to build such a map from robot perceptions while robots move autonomously to perform some tasks in the environment. We developped statistical learning approach (ie. a counting-based grid model) which computes in each cell the likelihoods of crossing a human in each possible direction, see red vectors in Fig. 14.a We extended the flow grid model with a human motion predictive model based on the Von Misses motion pattern, allowing to "accelerate" the flow grid mapping, see blue vectors in Fig. 14.a.

Then we examined how path-planning can benefit of such a flow grid, that is taking into account the risk for a robot to encounter humans in opposite direction. We first implemented the Flow-Grid model in a simulator built upon PedSim and ROS tools, allowing to simulate mobile robots and crowd of pedestrians. We compared three A*-based path-planning models using different levels of information about human presence: non-informed, a grid of human presence likelihood proposed by Tipaldi [83] and our grid of human motion likelihood (see 14.b). Experiments in simulations and with real robots allowed to show the efficiency of the flow-grid to build efficient paths through human flows (see 14.c). These results have been published in ECRM [16].

This work will allow us to develop new solutions to the patrolling of moving people, that we called the waiters problem two years ago (see our article in RIA revue, 2017 [11]). Indeed, if robots build a flow grid of people they cross and have to serve, they will be able to optimize along the time their strategy to deploy and revisit people regularly.

7.4.4. Navigation of telepresence robots

Participants: Rémi Cambuzat, Olivier Simonin, Anne Spalanzani, Gerard Bailly [GIPSA, CNRS, Grenoble], Frederic Elisei [GIPSA, CNRS, Grenoble].

In 2016 we obtained with the team of Gérard Bailly, from GIPSA/CNRS Grenoble, a regional support for the TENSIVE project. It funds the PhD thesis of Remi Cambuzat on immersive teleoperation of telepresence robots for verbal interaction and social navigation, started in October 2016. We have 2 mains objectives: i) to design a new generation of immersive control platforms for telepresence robots and ii) to teach multimodal behaviors to social robots by demonstration. In both cases, a human pilot interacts with remote interlocutors via the mediation of a robotic embodiment that should faithfully reproduce the body movements of the pilots while providing rich sensory and proprioceptive feedback. During social interactions, people's eyes convey a wealth of information about their direction of attention and their emotional and mental states. Endowing telepresence robots with the ability to mimic the pilot's gaze direction as well as autonomous social robots with the possibility to generate gaze cues is necessary for enabling them to seamlessly interact with humans. During the first year of the PhD thesis, we focused on the immersive teleoperation of the Nina Robot Gaze 15. Figure 15 abstracts the proposed methodology.

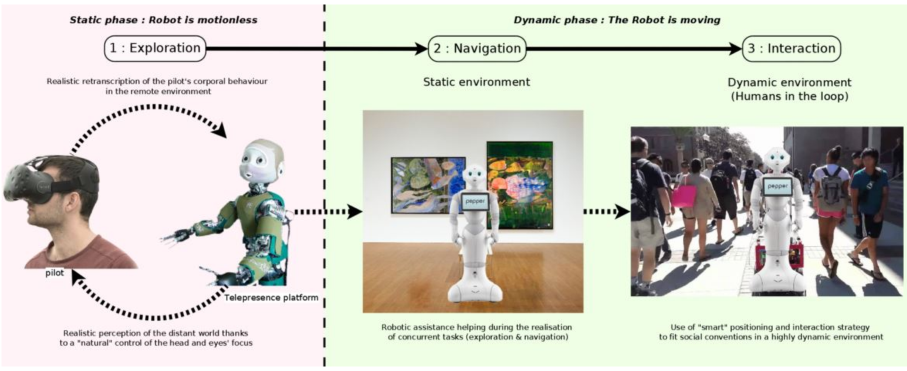

Figure 15. immersive teleoperation for social interaction

7.5. Decision Making in Multi-Robot Systems

7.5.1. Multi-robot planning in dynamic environments

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

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

After considering Multi-Robot Patrolling of known targets in 2016 [73], we generalized our work to Dynamic Multi Robot-Routing (DMRR), an instance of continuously adapting the multi-robot target allocation process (MRTA). 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. However, existent solutions do not regard the continuous adaptation of the ongoing robot missions to new targets. These techniques are neither adapted to handle the missions growth in time (nor a possible saturation bound for the mission cost). 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. We tested the algorithms on exhaustive sets of inputs. The results for DSAT shows it outperforms state-of-the-art methods, like standard SSI or SSI with regret clearing, especially in optimizing the target allocation w.r.t. the target coverage in time and the robot resource usage (e.g. minimizing the worst mission cost). Results have been submitted to ICAPS 2018.

This work is developped in the PhD. work of M. Popescu, but also through the collaboration (PHC [35] 'DRONEM' project) started in 2017 with the team of Gabriela Czibula from Babes-Bolyai University in Cluj-Napoca (Romania). The project focuses on optimization and online adaptation of the multi-cycle patrolling with machine learning (RL) techniques in order to deal with the arrival of new targets in the environment.

7.5.1.2. Global-local optimization in autonomous multi-vehicles systems

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

[35] Hubert Curien Partnership

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 [28]. We were surprise 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 tralleving 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 pointernet, 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 plan to extend this work in the multi-agent setting during the coming year.

7.5.2. Multi-robot coverage and mapping

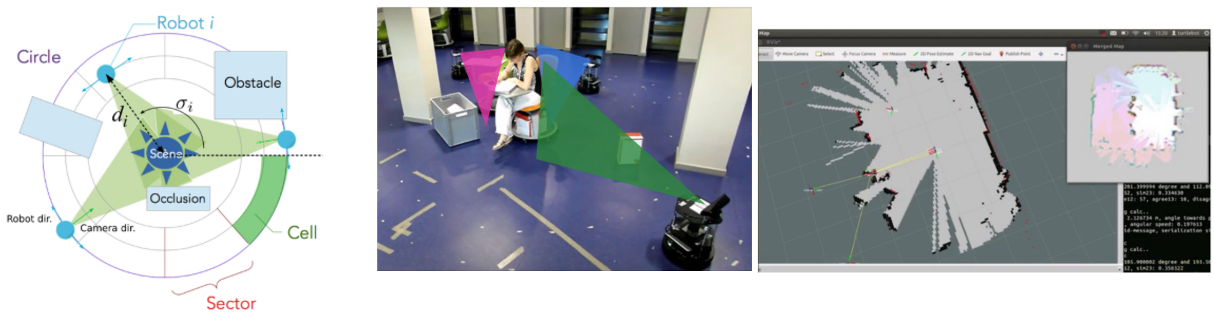

Figure 16. (a) Concentric navigation model. (b) Experimental setup and multi-robot mapping with Turtlebot 2.

7.5.2.1. Human scenes observation

Participants: Laetitia Matignon, Olivier Simonin, Stephane d'Alu, Christian Wolf.

Solving complex tasks with a fleet of robots requires to develop generic strategies that can decide in real time (or time-bounded) efficient and cooperative actions. This is particularly challenging in complex real environments. To this end, we explore anytime algorihms and adaptive/learning techniques.

The "CROME" and "COMODYS" [36] projects [37] are motivated by the exploration of the joint-observation of complex (dynamic) scenes by a fleet of mobile robots. In our current work, the considered scenes are defined as a sequence of activities, performed by a person in a same place. Then, mobile robots have to cooperate to find a spatial configuration around the scene that maximizes the joint observation of the human pose skeleton. It is assumed that the robots can communicate but have no map of the environment and no external localisation.

To attack the problem, we proposed an original concentric navigation model allowing to keep easily each robot camera towards the scene (see fig. 16.a). This model is combined with an incremental mapping of the environment and exploration guided by meta-heuristics in order to limit the complexity of the exploration state space. Results have been submitted to AAMAS'2018 [38].

[36] COoperative Multi-robot Observation of DYnamic human poSes
[37] Funded by a LIRIS transversal project in 2016-2017 and a FIL project in 2017-2019 (led by L. Matignon)
[38] *Multi-Robot Simultaneous Coverage and Mapping of Complex Scene - Comparison of Different Strategies*

In 2017, we also proposed an hybrid metric-topological mapping for multi-robot observation of a human scene. Robots are individually building a map that is updated cooperatively by exchanging only high-level data between robots, thereby reducing the communication payload. We combined an on-line distributed multi-robot decision with this hybrid mapping. These modules have been implemented and evaluated on our platform composed of several Turtlebots2, see fig. 16.b. Results have been published in 2017 in [21] (ECMR).

7.5.2.2. Multi-UAV Visual Coverage of Partially Known 3D Surfaces

Participants: Alessandro Renzaglia, Jilles Dibangoye, Olivier Simonin.

It has been largely proved that the use of Unmanned Aerial Vehicles (UAVs) is an efficient and safe way to deploy visual sensor networks in complex environments. In this context, a widely studied problem is the cooperative coverage of a given environment. In a typical scenario, a team of UAVs is called to achieve the mission without a perfect knowledge on the environment and needs to generate the trajectories on-line, based only on the information acquired during the mission through noisy measurements. For this reason, guaranteeing a global optimal solution of the problem is usually impossible. Furthermore, the presence of several constraints on the motion (collision avoidance, dynamics, etc.) as well as from limited energy and computational capabilities, makes this problem particularly challenging.

Depending on the sensing capabilities of the team (number of UAVs, range of on-board sensor, etc.) and the dimension of the environment to cover, different formulations of this problem can be considered. We firstly approached the deployment problem, where the goal is to find the optimal static UAVs configuration from which the visibility of a given region is maximized. A suitable way to tackle this problem is to adopt derivative-free optimization methods based on numerical approximations of the objective function. In 2012, Renzaglia et al. [74] proposed an approach based on a stochastic optimization algorithm to obtain a solution for arbitrary, initially unknown 3D terrains. However, adopting this kind of approaches, the final configuration can be strongly dependent on the initial positions and the system can get stuck in local optima very far from the global solution. We identified that a way to overcome this problem can be found in initializing the optimization with a suitable starting configuration. An a priori partial knowledge on the environment is a fundamental source of information to exploit to this end. The main contribution of our work is thus to add another layer to the optimization scheme in order to exploit this information. This step, based on the concept of Centroidal Voronoi Tessellation, will then play the role of initialization for the on-line, measurement-based local optimizer. The resulting method, taking advantages of the complementary properties of geometric and stochastic optimization, significantly improves the result of the previous approach 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. This work led to a paper submitted to ICRA 2018 [39], currently under review. The development of a realistic simulation environment based on Gazebo is an important on-going activity in Chroma and will allow us to further test the approach and to prepare the implementation of this algorithm on the real robotic platform available in the team.

We are currently also investigating the dynamic version of this problem, where the information is collected along the trajectories and the environment reconstruction is obtained from the fusion of the total visual data.

7.5.2.3. Middleware for open multi-robot systems

Participants: Stefan Chitic, Julien Ponge [CITI, Dynamid], Olivier Simonin.

Multi-robots systems (MRS) require dedicated software tools and models to face the complexity of their design and deployment. In the context of the PhD work of Stefan Chitic, we address service self-discovery and property proofs in an ad-hoc network formed by a fleet of robots. This led us to propose a robotic middleware, SDfR, that is able to provide service discovery, see [44]. In 2017, we defined a tool-chain based on timed automata, called ROSMDB, that offers a framework to formalize and implement multi-robot behaviors and to check some (temporal) properties (both offline and online). S. Chtic will defend his Phd thesis on March 2018.

[39] A. Renzaglia, J. Dibangoye and O. Simonin, "Multi-UAV Visual Coverage of Partially Known 3D Surfaces: Voronoi-based Initialization for Stochastic Optimization", IEEE International Conference on Robotics and Automation (ICRA), 2018, *under review*.

7.5.3. Sequential decision-making under uncertainty

This research is the follow up of team led by Jilles S. Dibangoye carried out during the last three years, which include foundations of sequential decision making by a group of cooperative or competitive robots or more generally agents.

7.5.3.1. Optimally solving cooperative and competitive games as continuous Markov decision processes

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

Our major findings this year include:

1. (Theoretical) – As an extension of [47] in the cooperative case, we characterize the optimal solution of partially observable stochastic games.
2. (Theoretical) – We further exhibit new underlying structures of the optimal solution for both cooperative and non-cooperative settings.
3. (Algorithmic) – We extend a non-trivial procedure for computing such optimal solutions when only an incomplete knowledge about the model is available.

This work proposes a novel 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 [40] for zs-POSGs, and coined them maximin (resp. minimax) equations. Even more importantly, we demonstrated Von Neumann & Morgenstern's minimax theorem [87] [88] holds in zs-POSGs. We further proved that value functions—solutions of maximin (resp. minimax) equations—yield special structures. More specifically, the maximin value functions are convex whereas the minimax value functions are concave. Even more surprisingly, we prove that for a fixed strategy, the optimal value function is linear. Together these findings allow us to extend planning and learning 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 [43].

7.5.3.2. Learning to act in continuous decentralized partially observable Markov decision process

Participants: Jilles S. Dibangoye, Olivier Buffet [Inria Nancy], Laëtitia Matignon, Christian Wolf, Guillaume Bono, Jacques Saradaryan, Olivier Simonin, Florian Peyreron.

During the last year, we investigated deep and standard reinforcement learning for solving decentralized partially observable Markov decision processes. Our preliminary results include:

1. (Theoretical) Proofs that the optimal value function is linear in the occupancy-state space, the set of all possible distributions over hidden states and histories.
2. (Algorithmic) Value-based and policy-based (deep) reinforcement learning for common-payoff partially observable stochastic games.

This work addresses a long-standing open problem of Multi-Agent Reinforcement Learning (MARL) in decentralized stochastic control. MARL previously applied to finite decentralized decision making with a focus on team reinforcement learning methods, which at best lead to local optima. In this research, we build on our recent approach [47], which converts the original problem into a continuous-state Markov decision process, allowing knowledge transfer from one setting to the other. In particular, we introduce the first optimal reinforcement learning method for finite cooperative, decentralized stochastic control domains. We achieve significant scalability gains by allowing the latter to feed deep neural networks. Experiments show our approach can learn to act optimally in many finite decentralized stochastic control problems from the literature.

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, Laetitia Matignon.

This collaboration has been built inside the INSA-VOLVO Chair, led by Prof. Didier Remond. In this context, the Chair funds the PhD Thesis of Guillaume Bono (2016-19). 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 a platoon of autonomous vehicles. This Post-Doc will start on February 2018.

8.1.2. Toyota Motor Europe (2006 - 2018)

Participant: Christian Laugier.

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 is on the process to be extended 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 been signed also.

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 2018 – 2020, with objective to address the open problem of emergency obstacle avoidance in complex traffic situations (for ADAS applications).

8.2.2. IRT Nanoelec – Perfect project (2012 - 2020)

Participants: Christian Laugier, Jerome Lussereau, Jean-Alix David.

Perfect is a project supported by ANR in the scope of the IRT (Technological Research Institute) Nanoelectronic driven by the CEA (Nuclear Energy Agency). The partners of the project are the CEA-LETI LIALP laboratory, ST-Microelectronics, Schneider Electric and Inria. The goal of this project is to propose integrated solutions for *Embedded Bayesian Perception for Dynamic Environment* and to develop integrated open platforms. The focus is on the application domain of autonomous mobile robots and vehicles, while considering both vehicle and infrastructure issues.

8.2.3. FUI Tornado (2017 – 2020)

Participants: Anne Spalanzani, Christian Laugier, Olivier Simonin, Jerome Lussereau, Jean-Alix David.

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. Several autonomous cars (Autonomous Renault Zoe) and one automatic Shuttle provided by EasyMiles will be customized and used. 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.

8.2.4. Cooperation with EasyMile (2017 – 2020)

Participants: Christian Laugier, Jerome Lussereau, Jean-Alix David.

A first successful Proof of Concept (PoC) of the implementation of our *CMCDOT* embedded system on the EV10 automatic Shuttle of EasyMile, has been performed during the first trimester of 2017. This work has been done in the scope of the Project Perfect of IRT Nanoelec, and it has conducted to very encouraging results. A multiannual workplan has been prepared in the scope of the IRT Nanoelec for transferring and adapting our technology to the EasyMile shuttles.

9. Partnerships and Cooperations

9.1. Regional Initiatives

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

Participants: Laetitia Matignon, Olivier Simonin, Alessandro Renzaglia, Jilles Dibangoye.

Project of the Informatics Federation of Lyon (FIL) between two teams of two laboratories: 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.

9.1.2. CORDES ADT Inria project, 2017-18

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

The project CORDES (Coordination d'une Flotte de Drones Connectés pour la Cartographie 3D d'édifices) is an Inria ADT coordinated by Olivier Simonin. It funds an Inria expert engineer position in Chroma (Vincent Le Doze, 10/17-11/19) focusing on UAVs control and path-planning. The project aims to deploy a fleet of UAVs able to autonomously fly over an unknown infrastructure and to build a 3D map.

9.1.3. Regional AAP ARC6 project, 2015-18

Participants: Olivier Simonin, Anne Spalanzani, Fabrice Valois [Insa de Lyon, Inria AGORA].

Regional project (Rhône-Alpes) "Mobilité au sein de flottes de robots sous contrainte de maintien de la connectivité" ARC6, 2015-2018. Leader : O. Simonin.

This project funds the PhD thesis of Mihai-Ioan Popescu, who started on november 2015, and co-advized by O. Simonin, A. Spalanzani and F. Valois. The project involves also the Pole de compétitivité "Via Meca".

9.1.4. Regional AAP ARC6 project 'TENSIVE', 2016-19

Participants: Remi Cambuzat, Gérard Bailly [CNRS, GIPSA Lab. Grenoble], Olivier Simonin, Anne Spalanzani.

Regional project (Rhône-Alpes) "TENSIVE Robots de TEléprésence : Navigation Sociale et Interaction VErbale immersives" ARC6, 2016-2019. Leader : G. Bailly.

This project funds the PhD thesis of Remi Cambuzat who started on october 2016, and co-advized by G. Bailly (Dir.), O. Simonin and A. Spalanzani.

9.2. National Initiatives

9.2.1. ANR

9.2.1.1. ANR "VIMAD" (2015-17)

The VIMAD project, led by A. Martinelli, aims at developing a robust and reliable perception system, only based on visual and inertial measurements, to enhance the navigation capabilities of fully autonomous micro aerial drones. It also aims at acquiring a deep theoretical comprehension of the problem of fusing visual and inertial measurements, by investigating its observability properties in challenging scenarios.

The activities related to this project, followed the work-plan (first year). They regarded the usage of our closed-form solution (recently published on the journal of computer vision, [64]) in the framework of micro aerial navigation in order to:

1. automatically perform state initialization;
2. improve the data matching process.

Additionally, the activities of VIMAD regarded the investigation of an unsolved problem in control theory, which is the unknown input observability problem in the nonlinear case, and its applications to the visual-inertial structure from motion problem.

See section 3.2.5 for a description of the results obtained during this year of the project.

9.2.1.2. ANR "Valet" (2016-18)

The ANR VALET project proposes a novel approach for solving car-sharing vehicles redistribution problem using vehicle platoons guided by professional drivers. An optimal routing algorithm is in charge of defining platoons drivers' routes to the parking areas where the followers are parked in a complete automated mode. The consortium is made of 2 academic partners : Inria (RITS, Chroma, Prima) and Ircyyn Ecole Centrale de Nantes and the AKKA company. The phD student (Pavan Vashista) recruited in this project focus 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 started in february 2016 and is codirected by D. Vaufreydaz (Inria/PervasiveInteraction).

9.2.1.3. ANR "HIANIC" (2017-20)

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 (Magma team) and LS2N laboratory (ARMEN and PACCE teams). A. Spalanzani is the leader of this project.

9.2.1.4. 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.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

Program: ECSEL

Project acronym: ENABLE-S3

Project title: European Initiative to Enable Validation for Highly Automated Safe and Secure Systems

Duration: June 2016 – May 2019

Coordinator: AVL List GesmbH

Other partners: Major European Organizations, including academic partners (such as Inria or KIT) and a Large number of industrial partners from various application domains such as automotive industry or Aeronautics or Train industry

Abstract: ENABLE-S3 is *industry-driven* and therefore aims to foster the leading role of the European industry. This is also reflected in its *use case driven approach*. The main technical objectives are extracted from the use cases defined by the industrial partners, in order to validate the success of the developed methods and tools.
The ENABLE-S3 project will provide European industry with leading-edge technologies that *support the development of reliable, safe and secure functions for highly automated and/or autonomously operating systems* by enabling the *validation and verification at reduced time and costs*.

Enables-S3 is a large European consortium, involving a French consortium leaded by Renault and Inria Grenoble Rhône-Alpes. The Inria Tamis team (Rennes) is also involved in the project.

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 (student exchanges and common project).

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).

9.4. International Initiatives

9.4.1. Inria International Labs

Program: International Center of Excellence

Duration: 2012 – 2017

Coordinator: C. Laugier

Other partners: UPMC & CNRS (France), NTU (Taiwan)

The iCeiRA [40] international robotics laboratory led by Prof. Ren Luo from NTU (Taiwan) and strongly supported by the Taiwanese government, has been launched in 2012 for 5 years. Christian Laugier (Inria) and Raja Chatila (UPMC & CNRS) have actively participated to the starting of this laboratory in 2012 and are external Principal Investigators. The addressed research is about the concept of Human centered robotics.

[40] International Center of Excellence in Intelligent Robotics and Automation Research.

9.4.2. Inria International Partners

9.4.2.1. Informal International Partners

- UC Berkeley & Stanford University (CA, USA)

  Subject: Autonomous Driving (postdoc in the scope of Inria@SV, common publications and patent).
- NUS Singapore & NTU Singapore.

  Subject: Autonomous Driving (visits, common ICT Asia project, common organization of workshops, review of PhD students).
- Massachussetts Institute of Technology (MIT), Cambridge, MA (USA)

  Subject: Decentralized Control of Markov Decision Processes.

  Subject: Autonomous Driving (visits and common organization of a workshop).

9.5. International Research Visitors

9.5.1. Visits of International Scientists

- Visits of researchers from University Babes-Bolyai, Cluj-Napoca (Romania). In the context of our PHC "DRONEM" (2017-18), some members from the MLyRE team visited CHROMA, at CITI lab. in Lyon, July 8-13. Prof. Gabriela Czibula, Dr. Istvan-Gergely Czibula, Dr. Marian Zsuzsanna-Edit and Diana Lucia-Miholca given some talks about Machine Learning.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. Member of the Organizing Committees

- O. Simonin was Sponsor Chair of ECAL 2017, the 14th European Conference on Artificial Life, organized in Lyon, September 4-8 (https://project.inria.fr/ecal2017/).
- C. Laugier, Ph. Martinet, C. Stiller and U. Nunes, organized a workshop entitled “9th Workshop on Planning, Perception and Navigation for Intelligent Vehicle” at IEEE IROS 2017, Vancouver (Canada), September 2017 (about 170 attendees). http://ppniv17.irccyn.ec-nantes.fr/
- C. Laugier co-organized with Suzanne Lesecq an Inria-CEA workshop on “Technologies for Autonomous vehicles”, Grenoble, February 2017. http://www.irtnanoelec.fr/organisation-dun-workshop-autour-des-technologies-du-vehicule-autonome/
- C. Laugier co-organized with Chao Lu a workshop at Beijing Institute of Technology (BIT) on “ Technologies for Autonomous Vehicles”, Beijing, May 2017.
- C. Laugier co-organized with NUS and MIT a workshop at IEEE ICRA 2017 entitled “ Workshop on Robotics and Vehicular Technologies for Self-Driving Cars”, Singapore, June 2017. http://cim.mcgill.ca/ malika/ICRA17_WS/
- C. Laugier has been appointed as Program co-chair for IEEE/RSJ IROS 2018 (Madrid) and General co-Chair of IEEE/RSJ IROS 2019 (Hong Kong).
- J. Dibangoye and O. Simonin co-organized the 1st Ecole d’Automne en IA, in Lyon, with Prof. C. Solnon (LIRIS, INSA Lyon) and the Pre-GDR IA, CNRS.
- F. Jumel is Member of Organizing Committees of the Robocup@Home league.
- F. Jumel is elected member of Technical Committees of the Robocup@Home league.

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

- C. Laugier was Associate Editor for IEEE/RSJ IROS 2017 (Vancouver), for IEEE ICRA 2017 (Singapore), and for IEEE ITSC 2017(Yokohama).

10.1.2.2. Member of the Conference Program Committees

- Jilles S. Dibangoye served, in quality of program committee member, for the following conferences: AAAI, IJCAI
- O. Simonin served, in quality of program committee member, for AAMAS (Autonomous Agent and Multi-agent Systems International Conference), Track Robotics.
- O. Simonin served, in quality of program committee member, for ICAPS (International Conference on Automated Planning and Scheduling), Track Robotics.
- O. Simonin served, in quality of program committee member and co-editor of the proceedings, for ECAL (European Conference on Artificial Life).
- O. Simonin is Program Committee member of the JFSMA conference since 2008 (Journées Francophones sur les Systèmes Multi-Agents).

10.1.2.3. Reviewer

- Agostino Martinelli served, in quality of reviewer, for the following conferences: ICRA, IROS, ACC.
- Jilles S. Dibangoye served, in quality of reviewer, for the following conferences: AAAI, IJCAI, ICRA.
- Olivier Simonin served, in quality of reviewer, for the following conferences: ICRA, IROS, ICAPS, ACC.

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 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 is a member of the editorial board of RIA Revue d'Intelligence Artificielle.

10.1.3.2. Reviewer - Reviewing Activities

- A. Martinelli served, in quality of reviewer, for the following journals: Transaction on Robotics, Transaction on Automatic Control, Transaction on Control System and Technology, Robotics and Automation Letters.
- Jilles S. Dibangoye served, in quality of reviewer, for the following journals: Revue d'Intelligence Artificielle, Mathematics and Artificial Intelligence Journal
- O. Simonin served, in quality of reviewer, for the following journals : Robotics and Autonomous Systems, Autonomous Robots (AURO) and RIA (Revue d'Intelligence Artificielle).

10.1.4. Invited Talks

- A. Martinelli was invited to give a talk at the Robotics and Perception Group at the university of Zurich, December 2017, "Closed form solution to cooperative visual inertial sensor fusion".
- Christian Laugier was invited to give a talk at the 4th journée "Mobilité Innovante: La sécurité Par et Pour les véhicules autonomes", Clermont-Ferrand, January 2017. Title: "Perception for risk prediction and autonomous driving" [14].

- Christian Laugier was invited to give a talk at the IS-Auto-Europe 2017, Dusseldorf, April 2017. Title: “Embedded Bayesian Perception and V2X Communication for Autonomous Driving” [13].
- Christian Laugier was invited to give a talk at the GTC 2017, San José, California, May 2017. Title: “Embedded Bayesian Perception and VTX Communication for Autonomous Driving” [17].
- Christian Laugier was invited to give a talk at the IEEE ICRA 2017 Workshop on Robotics and Vehicular Technologies for Self-Driving Cars, Jun 2017, Singapore, 2017. Title: “Embedded Bayesian Perception and Collision Risk Assessment” [12].
- Jilles S. Dibangoye was invited to give a talk at the MAFTEC group of the Artificial Intelligence GDR, Nov 2017. Title: “Learning to Act Optimally in Decentralized POMDPs”.
- C. Wolf was invited to a talk at DL2T : Deep Learning – Télédétection - Temps November 20th, 2017, Paris (Issy-Les-Moulineaux), France. Title: Apprentissage profond (Deep Learning) et séries temporelles : Concepts et mise en oeuvre.
- C. Wolf was invited to a talk at the conference Journées Nationale de la Recherche en Robotique. November 8th-10th, 2017, Biaritz, France. Title: Learning human centered computing for vision and robotics.
- C. Wolf was invited as a Keynote at European and Nordic Symposium on Multimodal Communication. October 17th, 2017. Title: Learning human motion: gestures, activities, pose, identity.

10.1.5. Leadership within the Scientific Community

- O. Simonin was elected in 2017 as member of the Board of AFIA, the French Association for Artificial Intelligence.
- C. Laugier is co-chair with Philippe Martinet and Christoph Stiller, of the IEEE RAS Technical Committee on “Autonomous Ground Vehicles and Intelligent Transportation Systems (AGVITS)”.
- C. Laugier is member of the Committee "safety of autonomous vehicles" (committee leaded by ARDI in the scope of the Innovation Regional Strategy).

10.1.6. Scientific Expertise

- C. Laugier is member of the Advisory Board of ISR University of Coimbra. He visited ISR in March 2017.
- C. Laugier is Scientific Advisor for the ProbaYes SA.
- C. Laugier have written a report on the concept of “Robot Taxi”for Renault-Nissan.
- O. Simonin was a member of the 2017 ANR scientific committee, and a reviewer, for the Interaction and Robotics call.
- O. Simonin was a reviewer for ANRT, CIFRE PhD thesis grant.
- O. Simonin was a reviewer for ANR ASTRID project submissions.
- A. Martinelli served, in quality of reviewer, for ANR project submissions.

10.1.7. Research Administration

- C. Laugier is a member of several Ministerial and Regional French Committees on Robotics and Autonomous Cars.
- O. Simonin is member of the Auvergne-Rhone-Alpes Robotics cluster (Coboteam), for Inria and INSA de Lyon entities.
- O. Simonin is member of the Scientific Council of the Digital League (Auvergne-Rhone-Alpes).
- A. Martinelli carried out the activity of leader for the ANR project VIMAD
- A. Martinelli carried out the activity of leader for the CARNOT project SEDIA
- F. Jumel is member of the board of IMAGINOVE cluster (digital content industry)
- F. Jumel is member of the Rhone-Alpes Robotics cluster (Coboteam)

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

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

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

INSA Lyon 3rd year : Jilles S. Dibangoye, Algorithmique et programmation, 76h, L3, Dept. Telecom INSA de Lyon, France.

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

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

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

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

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

INSA Lyon 5th year : O. Simonin, resp. of the Robotics option : AI for Robotics, Software and Hardware for robotics, Robotics projects, 60h, M2, Dept. Telecom INSA de Lyon, France.

INSA Lyon 3rd year : O. Simonin, Algorithmique et programmation, 30h, L3, Dept. Telecom INSA de Lyon, France.

INSA Lyon 5th year : A. Spalanzani, Navigation en environnement humain, 2h, M2, INSA de Lyon, France.

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.

Master: C. Laugier, “Bayesian Perception & Decision-making for Autonomous Vehicles and Mobile Robots”, 3 hours, Beijing Institute of Technology, Beijing, Chine.

Doctorat: C. Laugier, “Embedded Perception, Situation Awareness and Decision-making for Autonomous Vehicles”, 4 hours, Intelligent Vehicles International Summer School, ITEAM European H2020 MSCA-ITN project, Compiegne, France.

10.2.2. Supervision

PhD : Tiana Rakotovao Andriamahefa, Embedded Bayesian Perception on a Multi-core Architecture, Univ. Grenoble, 21/02/2017, C. Laugier and D. Ruspini (CEA LETI).

PhD in progress: David Sierra Gonzalez, Autonomous Driving (cooperation Toyota), 2014, C. Laugier, J. Dibangoye, E. Mazer (Inria Prima).

PhD in progress: Mathieu Barbier, Decision making for Intelligent Vehicles (cooperation Renault), 2015, C. Laugier, O. Simonin, E. Mazer (Inria Prima).

PhD in progress: Stefan Chitic, Middleware for multi-robot systems, 2013, O. Simonin, J. Ponge (CITI-Dynamid) (to be defended on March 2018).

PhD in progress: Mihai Popescu, Robot fleet mobility under communication constraints, 2015, O. Simonin, A. Spalanzani, F. Valois (CITI/Inria Agora).

PhD in progress: Pavan Vasishta, Situational Awareness of Autonomous Cars in Urban Areas, 2016, A. Spalanzani, Dominique Vaufreydaz (Inria Pervasive Interaction).

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: Remi Cambuzat, Robots de TEléprésence : Navigation Sociale et Interaction VErbale immersives, 2016, G. Bailly (CNRS GIPSA lab), A. Spalanzani, O. Simonin.

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

10.2.3. Juries

1. PhD thesis juries
   - C. Laugier was reviewer and member of the defense committee of the PhD thesis of Scott Drew Pendleton, NUS Singapore, April 2017.
   - O. Simonin was a reviewer and a member of the defense committee of the PhD thesis of Ange Nizard, Université Blaise Pascal, Clermont-Ferrand, February 4th, 2017.
   - O. Simonin was a reviewer and a member of the defense committee of the PhD thesis of Alexandre Lombard, UTBM (Univ. de Technologie de Belfort-Montbéliard), December 11, 2017.
   - A. Spalanzani was a reviewer and a member of the defense committee of the PhD thesis of Harmish Khambhaita, Université Toulouse III Paul Sabatier, October 2017.
   - Laetitia Matignon was a member of the defense committee of the PhD thesis of Nassim Kalde, Université de Lorraine, December 12th, 2017.
   - C. Wolf was reviewer and member of the defense committee of the PhD thesis of Enjie Ghorbel, Université de Normandie, October 10th, 2017.
   - C. Wolf was reviewer and member of the defense committee of the PhD thesis of Jorris Guerry, Ecole Polytechnique, November 20th, 2017.
   - C. Wolf was reviewer and member of the defense committee of the PhD thesis of Juan Manuel Perez Rua, Université de Rennes, December 4th, 2017.
   - C. Wolf was reviewer and member of the defense committee of the PhD thesis of Grigory Antipov, Télécom ParisTech, December 15th, 2017.
2. Member of commitee for Professor, Associate Prof., Research Director or Researcher recruitment
   - O. Simonin was a member of the jury of the Professor position at INSA Lyon, CITI Lab., on June 2017.

10.3. Popularization

- Laetitia Matignon participated to the « Fête de la Science » with a Turtlebot demonstration workshop (October 12th and 13th, Lyon, 2017).
- Olivier Simonin was invited by Université Populaire de Montelimar to give a talk about Autonomous Vehicles, on December 19.
- January 30, 2017,F. Jumel, Digital Summit, Hotel de Region Auvergne Rhone Alpes, Robotic Show
- February 2017, F. Jumel, FSM 2017, BU Sciences : Robotic Show : Dance with Baxter
- March 7,2017, F. Jumel, J. Saraydaryan FSM 2017, BU Sciences, Robotic show, Baxter and Co. (with R. Leber)
- June 9, 2017, F. Jumel, AGERA, “service robots, review of the state”
- October 10, 2017, F. Jumel , Conference IESF Lyon-RA , Where Artificial Intelligence Is Now (with L. Chen)
- November 9, F. Jumel, 2017 Scientific event of Open University of Lyon : “Intelligent robotics, between myth and reality”

- November 14, 2017, F. Jumel, IA event, IPL, “Presentation of Challenges of robocup”, (with P. Dominey, R. Lucazeau)
- November 23, 2017, F. Jumel, “Exposition Hello robots”, IUT Lyon 1 , “Smart robotic and Robocup”

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), 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] J. S. DIBANGOYE, O. BUFFET, O. SIMONIN. *Structural results for cooperative decentralized control models*, in "Proceedings of the twenty-fourth international joint conference on artificial intelligence, IJCAI 2015", Buenos Aires, Argentina, July 2015, https://hal.inria.fr/hal-01188481

[5] J. KAISER, A. MARTINELLI, F. FONTANA, D. SCARAMUZZA. *Simultaneous State Initialization and Gyroscope Bias Calibration in Visual Inertial aided Navigation*, in "IEEE Robotics and Automation Letters", January 2016, https://hal.archives-ouvertes.fr/hal-01423550

[6] 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

[7] T. RAKOTOVAO, J. MOTTIN, D. PUSCHINI, C. LAUGIER. *Multi-sensor fusion of occupancy grids based on integer arithmetic*, in "In 2016 IEEE International Conference on Robotics and Automation (ICRA)", 2016

[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] 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

[10] D. VASQUEZ. *Novel Planning-based Algorithms for Human Motion Prediction*, in "IEEE Conference on Robotics and Automation", Stockholm, Sweden, May 2016, forthcoming, https://hal.inria.fr/hal-01256516

Publications of the year

Articles in National Peer-Reviewed Journals

[11] J. SARAYDARYAN, F. JUMEL, O. SIMONIN. *Patrouille Multi-Agent Dynamique, application Robotique pour le Service de Personnes Mobiles*, in "Revue d'Intelligence Artificielle (RIA)", 2017, vol. 31, n^{o} 4, pp. 379-400 [*DOI :* 10.3166/RIA.31.379-400], https://hal.archives-ouvertes.fr/hal-01497878

Invited Conferences

[12] C. LAUGIER. *Embedded Bayesian Perception and Collision Risk Assessment: Invited Talk*, in "ICRA 2017 - IEEE International Conference on Robotics and Automation, Workshop on Robotics and Vehicular Technologies for Self-Driving Cars", Singapore, Singapore, June 2017, pp. 1-26, https://hal.inria.fr/hal-01672240

[13] C. LAUGIER. *Embedded Bayesian Perception for Autonomous Driving*, in "IS Auto Europe 2017", Dusseldorf, Germany, April 2017, https://hal.inria.fr/hal-01672171

[14] C. LAUGIER. *Perception for Risk Prediction and Autonomous Driving (invited talk)*, in "4ème Journée Mobilité Innovante "La sécurité pour et par les véhicules autonomes"", Clermont-Ferrand, France, IMOBS3 et VIAMECA, January 2017, https://hal.inria.fr/hal-01672303

International Conferences with Proceedings

[15] M. BARBIER, C. LAUGIER, O. SIMONIN, J. IBANEZ-GUZMAN. *Classification of Drivers Manoeuvre for Road Intersection Crossing with Synthetic and Real Data*, in "2017 IEEE intelligent Vehicles Symposium", Los Angeles, United States, proceedings of the 2017 IEEE intelligent Vehicles Symposium, IEEE Intelligent Transportation Systems Society, June 2017, 7 p. , https://hal.inria.fr/hal-01519709

[16] F. JUMEL, J. SARAYDARYAN, O. SIMONIN. *Mapping likelihood of encountering humans: application to path planning in crowded environment*, in "The European Conference on Mobile Robotics (ECMR)", Paris, France, Proceedings of ECMR 2017, September 2017, https://hal.archives-ouvertes.fr/hal-01588815

[17] C. LAUGIER. *Embedded Bayesian Percpetion and V2X Communication for Autnomous Driving*, in "GPU Technology Conference - GTC 2017", San Jose, California, United States, May 2017, https://hal.inria.fr/hal-01672113

[18] 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

[19] A. MARTINELLI. *The Unicycle in Presence of a Single Disturbance: Observability Properties*, in "CT 2017 - SIAM Conference on Control and its application", Pittsburgh, United States, 2017 Proceedings of the Conference on Control and its Applications, SIAM, July 2017, pp. 1-8 [*DOI :* 10.1137/1.9781611975024.9], https://hal.inria.fr/hal-01669038

[20] A. MARTINELLI, A. RENZAGLIA. *Cooperative Visual-Inertial Sensor Fusion: Fundamental Equations*, in "MRS 2017 - The 1st International Symposium on Multi-Robot and Multi-Agent Systems", Los Angeles, United States, December 2017, pp. 1-8, https://hal.inria.fr/hal-01668972

[21] L. MATIGNON, S. D'ALU, O. SIMONIN. *Multi-robot human scene observation based on hybrid metric-topological mapping*, in "European Conference on Mobile Robotics", Paris, France, September 2017, https://hal.archives-ouvertes.fr/hal-01553064

[22] V. ROMERO-CANO, N. VIGNARD, C. LAUGIER. *XDvision: Dense outdoor perception for autonomous vehicles*, in "IEEE Intelligent Vehicle conference 2017 (IV 2017)", Redondo Beach, Los Angeles, United States, June 2017 [*DOI :* 10.1109/IVS.2017.7995807], https://hal.inria.fr/hal-01672089

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