Activity Report 2011

Project-Team IMARA

Informatics, Mathematics and Automation for La Route Automatisée

RESEARCH CENTER
Paris - Rocquencourt

THEME
Robotics

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Project-Team IMARA

Keywords: Intelligent Transportation Systems, Computer Vision, Robotics, Stochastic Modeling, Robot Motion, Quality Of Service, Safety, Signal Processing, SLAM

1. Members

Research Scientists

Fawzi Nashashibi [Team leader, HdR]
Arnaud de La Fortelle [Prof. ENSMP, HdR]
Philippe Deschamp [Researcher]
André Ducrot [Senior Researcher, until July]
Thierry Ernst
Guy Fayolle [Senior Researcher, Emeritus, HdR]
Gérard Le Lann [Senior Researcher, Emeritus, HdR]
Jean-Marc Lasgouttes [Junior Researcher]

External Collaborators

Cyril Furtlehner [Junior Researcher, TAO (INRIA Saclay)]
Michel Parent [Former team leader, until October 2010]
Laurent Bouraoui [Armines]

Technical Staff

Armand Yvet [AI]
Michel Contet [since October]
Ines Ben Jemaa
Clément Boussard
François Charlot
Carlos Holguin
Arnaud Lewden [until October]
Paulo Lopes Resende
Anne-Charlotte Nicoud
Cristian Sandu [until June]
Jianping Xie
Feng You [until July]
Ronghui Zhang [until January]
Thouraya Toukabri
Jong-Hyouk Lee
Tony Noël [Exoteek]

PhD Students

Hao Li
Benjamin Lefaudeux
Mohamed Marouf
Victorin Martin
Luis Alfredo Martinez-Gomez
Olivier Mehani
Manabu Tsukada
Satoru Noguchi [NAIST]

Post-Doctoral Fellow

Maxim Samsonov [until March]

Visiting Scientists

Plamen Petrov [Prof. Tech. Univ. of Sofia – Bulgaria, July to September]
Adriano Alessandrini [Prof. Univ. of Roma La Sapienza – Italy, February to April]

Administrative Assistant

Chantal Chazelas [AI]

2. Overall Objectives

2.1. Introduction

The focus of the project-team is to develop the technologies linked to Intelligent Transportation Systems (ITS) with the objective to achieve sustainable mobility by the improvement of the safety, the efficiency and the ease of use of road transport according to the recent "Intelligent Vehicle Initiative" launched by the DG Information Society of the European Commission (for "Smarter, Cleaner, and Safer Transport").

More specifically, we want to develop, demonstrate and test some innovative technologies under the framework of "La Route Automatisée" which covers all the advanced driver assistance systems (ADAS) and the traffic management systems going all the way to fully automated vehicles.

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

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

1. the control of individual road vehicles to improve locally their efficiency and safety,
2. the modelling and control of large transportation systems.

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

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

These two themes are largely dependent on the expertise of numerous project teams within INRIA and the past developments of IMARA's activities (or previous activities carried under the Praxitèle R&D team) have been largely done in cooperation with these teams. Conversely, these teams have often been fed by technical challenges brought by IMARA. We can mention for example mathematical models developed to forecast traffic, image processing techniques to localise precisely a mobile in its environment, new network protocols to insure connectivity between highly mobile units...

2.2. Highlights

- Year 2011 was a particular year, where the emblematic leader of IMARA – Michel Parent – has retired but remained a close collaborator with the team. His successor Fawzi Nashashibi is the new team leader.
- 2011 also saw the retirement of André Ducrot, who has been working for many years on image processing and lately visual odometry. Among the colleagues who left Imara this year, we would like to mention in particular Philippe Deschamps, who passed away last October. Philippe has been a researcher in several teams of Inria for more than thirty years.
- 2011 was also the end of several European projects: HAVEit, Intersafe-2, CityMobil and CityNet-Mobil. CityMobil showcases and the involvement of INRIA in the final event constituted a true breakthrough from the scientific and team visibility points of view. Thanks to the Cybercars service at La Rochelle, IMARA proved its leadership by performing a unique on-demand urban transportation system based on automated electric vehicles called Cybus.

3. Scientific Foundations

3.1. Autonomous driving and sustainable mobility

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

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

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

3.1.1. Perception of the road environment

The perception and understanding of the environment is the key element which is needed whatever the application is (information to the driver, helping the driver or substitution of the driver). This research area continues therefore to be a focus point of our research. It starts with the processing of data from various sensors, the cameras being the most ubiquitous ones because of their large capabilities to apprehend the dynamic 3D environment. Obviously, fusion of data with various other sensors is also a focus of the research, since cameras alone cannot apprehend every possible complex situation. We already have large experience with Lidars (Ibeo) and we will now integrates also radar sensors in the fusion approach.

However, sensing the environment alone is not sufficient for the most complex road situation to help or replace the driver. We have to understand the situation, however complex it is. This is another key area of our research, which relies on various types of coding techniques to store the information about the environment and to interpret it. For example, we have coded the information using ontologies, allowing various subsystems of the vehicle or several vehicles to share information. We also store the environment information in normalized space-time representations to deal with the differences between road infrastructures measured in terms of their geometry and object entities.

We plan for example to use directed positional acyclic labelled graphs (DPAG's) to cope with very complex situations. Communications between the vehicles can also use this formalism. Using information from others, the vehicle can reduce the uncertainty of its local model and extend its coverage (see beyond what the vehicle in front sees, the one of the other lane sees).

3.1.2. Planning vehicle actions

The second level of our research on vehicle control concerns the planning of the actions to be taken. From the understanding of the situation, we have either to warn the driver, to help him in the control of his vehicle, or to take control in case of a driverless vehicle. In simple situations, the planning might also be quite simple, but in the most complex situations we want to explore, the planning must involve complex algorithms dealing with the trajectories of the vehicle and its surroundings (which might involve other vehicles and/or fixed or moving obstacles). In the case of fully automated vehicles, the perception will involve some map building of the environment and obstacles, and the planning will involve partial planning with periodical recomputation to reach the long term goal. In this case, with vehicle to vehicle communications, what we want to explore is the possibility to establish a negotiation protocol in order to coordinate nearby vehicles (what humans usually do by using driving rules, common sense and/or non verbal communication).

The idea of using communication to enhance map building or coordinating robots to achieve a task is not new. However, the vast majority of the works are done under constrains that are unrealistic for the urban environment scenario. Typical assumptions are perfect knowledge of the robots position and perfect communication (no delay, infinite throughput).

Even overlooking this, most of the algorithms do not match the application scenario where vehicles are expected to be part of a traffic flow, where sudden stops, forcing multiple encounters, revisiting places are not acceptable behaviours. The best teams in the world which took part of the DARPA Urban Challenge demonstrated that these problems have not yet been fully addressed.

3.1.3. Execution control

The third level of our research on vehicle control concerns the execution of the actions which have been elaborated at the two first levels. Obviously, this does not concern applications where only advice is given to the driver. Here, we have to execute in real-time a particular action or set of actions. The research we want to conduct is mostly centered on the software tools to implement such real-time actions in an accurate and safe way. This is a difficult problem, which is the focus of many industrial projects with the development of standards for interfaces and development procedures.

The project-team builds on its experience with the development of safety critical software for the operation of its cybercars to take part of these standards, in particular in the field of fail-safe software and redundant architectures.

3.2. Sensors and information processing

Participants: Fawzi Nashashibi, Benjamin Lefaudeux, André Ducrot, Jianping Xie, Laurent Bouraoui, Paulo Lopes Resende, Hao Li.

3.2.1. Sensors and single-sensor information processing

The first step in the design of a control system are sensors and the information we want to extract from them, either for driver assistance or for fully automated guided vehicles. We put aside the proprioceptive sensors, which are rather well integrated. They give information on the host vehicle state, such as its velocity and the steering angle information. Thanks to sensor data processing, several objectives can be reached. The following topics are some applications validated or under development in our team:

- localization of the vehicle with respect to the infrastructure, i.e. lateral positioning on the road can be obtained by mean of vision (lane markings) or by mean of magnetic, optic or radar devices;
- detection and localization of the surrounding vehicles and determination of their behavior can be obtained by a mix of vision, laser or radar based data processing;
- detection of obstacles other than vehicles (pedestrians, animals objects on the road, etc.) that requires multisensor fusion techniques;
- simultaneous localization and mapping as well as mobile object tracking using a generic and robust laser based SLAMMOT algorithm.

Since INRIA is very involved in image processing, range imaging and multisensor fusion, IMARA emphasizes vision techniques, particularly stereo-vision, in relation with Kumamoto Lab (Japan), LITIS (Rouen) and Mines ParisTech.

3.2.1.1. Disparity Map Estimation

Participants: Laurent Bouraoui, André Ducrot, Fawzi Nashashibi, Hao Li, Benjamin Lefaudeux.

In a quite innovative approach presented in last year's report, we developed the Fly Algorithm, an evolutionary optimisation applied to stereovision and mobile robotics. Although successfully applied to real-time pedestrian detection using a vehicle mounted stereohead (see LOVe project), this technique couldn't be used for other robotics applications such as scene modeling, visual SLAM, etc. The need is for a dense 3D representation of the environment obtained with an appropriate precision and acceptable costs (computation time and resources).

Stereo vision is a reliable technique for obtaining a 3D scene representation through a pair of left and right images and it is effective for various tasks in road environments. The most important problem in stereo image processing is to find corresponding pixels from both images, leading to the so-called disparity estimation. Many autonomous vehicle navigation systems have adopted stereo vision techniques to construct disparity maps as a basic obstacle detection and avoidance mechanism.

We also worked in the past on an original approach for computing the disparity field by directly formulating the problem as a constrained optimization problem in which a convex objective function is minimized under convex constraints. These constraints arise from prior knowledge and the observed data. The minimization process is carried out over the feasibility set, which corresponds to the intersection of the constraint sets. The construction of convex property sets is based on the various properties of the field to be estimated. In most stereo vision applications, the disparity map should be smooth in homogeneous areas while keeping sharp edges. This can be achieved with the help of a suitable regularization constraint. We propose to use the Total Variation information as a regularization constraint, which avoids oscillations while preserving field discontinuities around object edges.

The algorithm we are developing to solve the estimation disparity problem has a block-iterative structure. This allows a wide range of constraints to be easily incorporated, possibly taking advantage of parallel computing architectures. This efficient algorithm allowed us to combine the Total Variation constraint with additional convex constraints so as to smooth homogeneous regions while preserving discontinuities.

Finally, we are currently working on an original stereo-vision based SLAM technique based on the detection and the registration of interest keypoints. The system is supposed to perform 3D mapping but also a 3D localization of the ego vehicle using Monte Carlo and RANSAC techniques.

3.2.2. Cooperative Multi-sensor data fusion

Participants: Fawzi Nashashibi, Yann Dumortier, André Ducrot, Jianping Xie, Laurent Bouraoui, François Charlot, Hao Li.

Advanced Driver Assistance System (ADAS) and Cybercars applications are moving towards vehicle-infrastructure cooperation. In such scenario, information from vehicle based sensors, roadside based sensors and a priori knowledge is generally combined thanks to wireless communications to build a probabilistic spatio-temporal model of the environment. Depending on the accuracy of such model, very useful applications from driver warning to fully autonomous driving can be performed.

IMARA has developed a framework for data acquisition, spatio-temporal localization and data sharing. Such system is based on a methodology for integrating measures from different sensors in a unique spatio-temporal frame provided by GPS receivers/WGS-84. Communicant entities, i.e. vehicles and roadsides exhibit and share their knowledge in a database using network access. Experimental validation of the framework was performed by sharing and combining raw sensor and perception data to improve a local model of the environment. Communication between entities is based on WiFi ad-hoc networking using the Optimal Link State Routing (OLSR) algorithm developed by the HIPERCOM research project at INRIA.

The Collaborative Perception Framework (CPF) is a combined hardware/software approach that permits to see remote information as its own information. Using this approach, a communicant entity can see another remote entity software objects as if it was local, and a sensor object, can see sensor data of others entities as its own sensor data. Last year's developments permitted the development of the basic hardware pieces that ensures the well functioning of the embedded architecture including perception sensors, communication devices and processing tools. The final architecture was relying on the *SensorHub* presented in year 2010 report. This year, we focused on the development of applications and demonstrators using this unique architecture:

- A canonical application was developed to demonstrate the ability of platooning using vehicle-to-vehicle communications to exchange vehicles absolute positions provided by respective GPS receivers. This approach was presented at the ITS World Congress under the form of a cooperative driving demonstration with communicant vehicles. This demonstration was also the context of an international collaboration involving our team, the robotics center of ENSMP and the SwRI (see Section 8.3).
- A similar demonstration was presented in the context of the international workshop on "The automation for urban transport" that was held in the french city of La Rochelle. Here three Cycabs have shown platooning capacities and demonstrated the ability of supervising collision free insertion at an intersection. The Intersection Collision Warning System (ICWS) application was built here on top of CPF to warn a driver in case of potential accident. It relies on precise spatio-temporal localization of entities and objects to compute the Time To Collision (TTC) variables but also on a "Control Center" that collects the vehicles positions and sends back to them the appropriate instructions and speed profiles.
- In the context of the HAVEit project we have developed a vehicle-to-vehicle and infrastructure-to-vehicle communication system capable of providing relevant data to the Co-pilot system (also developed by INRIA). This data is processed in order to be taken into account in the manoeuvre planning and the trajectory planning algorithms.
- The use of vehicle-to-vehicle communications allows an improved on-board reasoning since the decision is made based on an extended perception.

Finally, since vehicle localization (ground vehicles) is an important task for intelligent vehicle systems, vehicle cooperation may bring benefits for this task. A new cooperative multi-vehicle localization method using split covariance intersection filter is under investigation and development and first results are now available. In this approach, each vehicle computes its own position thanks to its own sensors. It maintains an estimate of a decomposed group state and this estimate is shared with neighboring vehicles; the estimate of the decomposed group state is updated with both the sensor data of the ego-vehicle and the estimates sent from other vehicles; the covariance intersection filter which yields consistent estimates even facing unknown degree of inter-estimate correlation has been used for data fusion.

Associated projects: Sharp, Icare, Complex.

3.3. Path planning and trajectory generation

Participants: Laurent Bouraoui, Fawzi Nashashibi, Plamen Petrov, Paulo Lopes Resende, Clément Boussard, Cristian Sandu.

We tackle two main topics: robot (or vehicle) control and path planning.

Control addresses the command system designed to execute at best the orders given by either the driver (assisted by the system) or the automated driving system (the co-pilot). The command system sends orders to the mechanical parts of the vehicles using all the information raised by the sensors or coming from path planner or an advanced co-pilot.

The real difficulty with this kind of control comes from the complexity of the dynamic behavior of the vehicle: response are highly non linear, particularly the response to forces of the tires on various soils. INRIA has a great expertise in these control problems and IMARA already demonstrated solutions for automatic driving of platoons of electrical cars. This research is still an active field. We recently designed and integrated a modular control architecture dedicated to the Cycabs. The system's low level is based on a DSPIC architecture while the system management and core system integrates the Syndex system developed by the AOSTE project-team.

From the modeling point of view, we want to enhance the system concerning the speed, the variety of wheel-soil contact. The lateral control problem is also studied, particularly in view of drivers assistance. This is studied jointly with our LaRA partners (Robotics Center of ENSMP).

Path planning is another aspect of command systems dedicated to the generation of correct trajectories for an autonomous mobile robot (Cycabs) and for the autonomous mode of a vehicle. We currently work on a generic planner capable of finding secure trajectories for both robots and intelligent vehicles.

Associated projects: Sharp, Icare, Sosso, E-Motion.

3.4. Managing the system (via probabilistic modeling)

Participants: Guy Fayolle, Cyril Furtlehner, Arnaud de La Fortelle, Jean-Marc Lasgouttes, Sami Mahari, Victorin Martin.

The research on the management of the transportation system is a natural continuation of the research of the Preval team, which joined IMARA in 2007. For many years, the members of this team (and of its ancestor Meval) have been working on understanding random systems of various origins, mainly through the definition and solution of mathematical models. The traffic modelling field is very fertile in difficult problems, and it has been part of the activities of the members of Preval since the times of the Praxitèle project.

Following this tradition, the roadmap of the group is to pursue basic research on probabilistic modelling with a clear slant on applications related to LaRA activities. A particular effort is made to publicize our results among the traffic analysis community, and to implement our algorithms whenever it makes sense to use them in traffic management. Of course, as aforementioned, these activities in no way preclude the continuation of the methodological work achieved in the group for many years in various fields: random walks in Z_+^n ([2], [3], [6]), large deviations ([1], [8]) birth and death processes on trees, particle systems. The reader is therefore encouraged to read the recent activity reports for the Preval team for more details.

In practice, the group explores the links between large random systems and statistical physics, since this approach proves very powerful, both for macroscopic (fleet management [5]) and microscopic (car-level description of traffic, formation of jams) analysis. The general setting is mathematical modelling of large systems (mostly stochastic), without any a priori restriction: networks [4], random graphs or even objects coming from biology. When the size or the volume of those structures grows (this corresponds to the so-called thermodynamical limit), one aims at establishing a classification based on criteria of a twofold nature: quantitative (performance, throughput, etc) and qualitative (stability, asymptotic behavior, phase transition, complexity).

3.4.1. Exclusion processes

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

Most of these generalizations lead to models that are obviously difficult to solve and require upstream theoretical studies. Some of them models have already been investigated by members of the group, and they are part of wide ongoing research.

3.4.2. Message passing algorithms

Large random systems are a natural part of macroscopic studies of traffic, where several models from statistical physics can be fruitfully employed. One example is fleet management, where one main issue is to find optimal ways of reallocating unused vehicles: it has been shown that Coulombian potentials might be an efficient tool to drive the flow of vehicles. Another case deals with the prediction of traffic conditions, when the data comes from probe vehicles instead of static sensors. Using some famous Ising models together with the Belief Propagation algorithm very popular in the computer science community, we have been able to show how real-time data can be used for traffic prediction and reconstruction (in the space-time domain).

This new use of BP algorithm raises some theoretical questions about the properties of the Bethe approximation of Ising models

- how do the stability of the BP fixed points relate the the minima of the free energy?
- what is the effect of the various extensions to BP (fractional, tree-reweighted, region-based,...) of these fixed points?
- what is the behaviour of BP in the situation where the underlying data have many different statistical components, representing a variety of independent patterns?

3.5. Communications with vehicles

Participants: Thierry Ernst, Manabu Tsukada, Olivier Mehani, Jong-Hyouk Lee, Satoru Noguchi, Ines Ben Jemaa, Hongliang Zhang.

As witnessed by standardization activities, conferences, research work and ITS projects around the world, Internet-based communications in vehicular networks is now under the spotlight. Most of the research and development work in this area is only considering the Internet for multimedia communications or together with the use of 3G cellular links for Internet-based communications. Few teams are investigating the use of the TCP/IP suite of protocols and their extensions for real vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, i.e. not only for multimedia, but also for navigation and safety purposes where critical data are exchanged over the air between vehicles. Based on our expertise in both Internet-based communications in the mobility context and in ITS, we are now investigating the use of IPv6 (Internet Protocol version 6 which is going to replace the current version, IPv4, in a few years from now) for vehicular communications, in a combined architecture allowing both V2V and V2I.

Short term objectives in this domain is the development of routing protocols which are fast enough to allow cooperative manoeuvres between cybercars, the specification of IPv6 mobility features that will improve the known routing inefficiencies and the performance analysis of existing routing and path selection mechanisms. New standards for vehicle to vehicle communications are also expected from this activity through our involvement in standardization bodies (ISO, IETF and ETSI).

Longer term activities include studying novel routing mechanisms such as a geographic addressing and routing (geonetworking), specifying mechanisms that will allow to guarantee a minimum quality of service while a vehicle is moving across heterogeneous access networks, and the analysis of security threats on the vehicular networks. All of these are parts of our objective to provide a packet-switched communication architecture suitable for the vehicular networks needs.

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

3.5.1. Combination of MANET and NEMO

Mobile Adhoc Network (MANET) – or more precisely VANET (Vehicular Adhoc Network) in our specific case – routing protocols are mostly used for vehicle-vehicle communications and network mobility (NEMO) support protocols to maintain the Internet access for vehicle-infrastructure communications. The necessary interaction between MANET and NEMO (known as MANEMO) brings a number of technical and scientific issues in terms of addressing requirements (infrastructure-less vs infrastructure-based), improved routing (routing optimization) and improved network accessibility (multihoming) because protocols have been specified independently from one another. In addition, we are investigating new routing protocol approaches adapted for the vehicular network characteristics. This includes GeoNetworking where a certain information, particularly safety information, is delivered to all or a set of vehicles located in a specific geographic area with minimum network overhead and minimum latency. GeoNetworking is the favored approach in the automotive industry.

3.5.2. Multihoming in Nested Mobile Networks with Route Optimization

Network mobility has the particularity of allowing recursive mobility, i.e. where a mobile node is attached to another mobile node (e.g. a PDA is attached to the in-vehicle IP network). This is referred to as nested mobility and brings a number of research issues in terms of routing efficiency. Another issue under such mobility configurations is the availability of multiple paths to the Internet (still in the same example, the PDA has a 3G interface and the in-vehicle network has some dedicated access to the Internet) and its appropriate selection.

3.5.3. Service Discovery

Vehicles in a close vicinity need to discover what information can be made available to other vehicles (e.g. road traffic conditions, safety notification for collision avoidance). We are investigating both push and pull approaches and the ability of these mechanisms to scale to a large number of vehicles and services on offer.

3.5.4. Quality of Service (QoS)

The use of heterogeneous wireless technologies for vehicular networks incur varying delivering delays or loss, though safety and some non-safety data must be transmitted in a bounded time frame. Also, these wireless technologies are often offered by various access network operators with different billing and filtering policies. We therefore need to investigate into mechanisms to provision network resources across access networks with different characteristics.

3.5.5. Security

Data exchanged between vehicles must be clearly authenticated and should guarantee the privacy of the vehicle user, as much from a location point of view as from a data content point of view. Mechanisms must be embedded into the communication architecture to prevent intruder to corrupt the system which could cause accidents and traffic congestion as a result of overloading the network or targeting a vehicle with forged or fake information.

4. Application Domains

4.1. Introduction

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

4.2. Driving assistance

Several techniques will soon help drivers. One of the first immediate goal is to improve security by alerting the driver when some potentially dangerous or dangerous situations arise, i.e. collision warning systems or lane tracking could help a bus driver and surrounding vehicle drivers to more efficiently operate their vehicles. Human factors issues could be addressed to control the driver workload based on additional information processing requirements.

Another issue is to optimize individual journeys. This means developing software for calculating optimal (for the user or for the community) path. Nowadays, path planning software is based on a static view of the traffic: efforts have to be done to take the dynamic component in account.

4.3. New transportation systems

The problems related to the abusive use of the individual car in large cities led the populations and the political leaders to support the development of public transport. A demand exists for a transport of people and goods which associates quality of service, environmental protection and access to the greatest number. Thus the tram and the light subways of VAL type recently introduced into several cities in France conquered the populations, in spite of high financial costs.

However, these means of mass transportation are only possible on lines on which there is a keen demand. As soon as one moves away from these “lines of desire” or when one deviates from the rush hours, these modes become expensive and offer can thus only be limited in space and time.

To give a more flexible offer, it is necessary to plan more individual modes which approach the car as we know it. However, if one wants to enjoy the benefits of the individual car without suffering from their disadvantages, it is necessary to try to match several criteria: availability anywhere and anytime to all, lower air and soils pollution as well as sound levels, reduced ground space occupation, security, low cost.

Electric or gas vehicles available in self-service as in the Praxitèle system bring a first response to these criteria. To be able to still better meet the needs, it is however necessary to re-examine the design of the vehicles on the following points:

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

These systems are now operating (i.e. in La Rochelle). The challenge is to bring them to an industrial phase by transferring technologies to these still experimental projects.

4.4. Cybercars

The long term effort of the project is to put automatically guided vehicles (cybercars) on the road. It seems too early to mix cybercars and traditional vehicles, but data processing and automation now make it possible to consider in the relatively short term the development of such vehicles and the adapted infrastructures. IMARA aims at using these technologies on experimental platforms (vehicles and infrastructures) to accelerate the technology transfer and to innovate in this field.

Other application can be precision docking systems that will allow buses to be automatically maneuvered into a loading zone or maintenance area, allowing easier access for passengers, or more efficient maintenance operations. Transit operating costs will also be reduced through decreased maintenance costs and less damage to the breaking and steering systems.

Regarding technical topics, several aspects of Cybercars have been developed at IMARA this year. First, we have stabilized a generic Cycab architecture involving INRIA Syndex tool and CAN communications. The critical part of the vehicle is using a real time Syndex application controlling the actuators via two Motorola’s MPC555. Today, we have decided to migrate to the new dsPIC architecture for more efficiency and ease of use.

This application has a second feature, it can receive commands from an external source (Asynchronously this time) on a second CAN bus. This external source can be a PC or a dedicated CPU, we call it high level. To work on the high level, in the past years we have been developing a R&D framework called (Taxi) which used to take control of the vehicle (Cycab and Yamaha) and process data such as gyro, GPS, cameras, wireless communications and so on. Today, in order to rely on a professional and maintained solution, we have chosen to migrate to the RTMAPS SDK development platform. Today, all our developments and demonstrations are using this efficient prototyping platform. Thanks to RT-MAPS we've been able to do all the demonstrations on our cybercars: cycabs, Yamaha AGV and new Cybus platforms. These demonstrations include : reliable SLAMMOT algorithm using 2 to 4 laser sensors simultaneously, automatic line/road following techniques, PDA remote control, multi sensors data fusion, collaborative perception via ad-hoc network.

The second main topic is inter-vehicle communications using ad-hoc networks. We have worked with the HIPERCOM team for setting and tuning OLSR, a dynamic routing protocol for vehicles communications (see Section 3.5). Our goal is to develop a vehicle dedicated communication software suite, running on a specialised hardware. It can be linked also with the Taxi Framework for getting data such GPS information's to help the routing algorithm.

5. Software

5.1. ElevatorRoutePlanner

Participants: Fawzi Nashashibi [correspondant], Paulo Lopes Resende.

This software is dedicated to the building of a decision system that performs task planning and especially route planning for a multiple vehicles based system. Each vehicle sends remotely and asynchronously its position and speed to the system and the "elevator route planner" decides for the destination of each vehicle among a predefined map of fixed stations. Since the stations are on one side of the road, the vehicles are possibly sharing the same stations, leading sometimes to conflictual situations the system has to solve.

- Version: V1

5.2. MELOSYM

Participants: Fawzi Nashashibi [correspondant], Jianping Xie.

MELOSYM is the acronym for "**M**odélisation de l'**E**nvironnement et **LO**calisation en temps réel pour un **SY**stème **M**obile autonome ou pas, fondé sur des données du capteur laser". This is a SLAM based algorithm for the environment mapping and vehicle localisation in real time using laser data. The particularity of the algorithm is its hierarchical approach that improves the accuracy of the system and speeds up the computations.

- Version: V1

5.3. ObstaclesDetectionLaser

Participants: Fawzi Nashashibi [correspondant], Paulo Lopes Resende, Laurent Bouraoui.

This is a software for obstacle detection by processing laser range finders data and return the position and distance of the nearest obstacle with regard to the vehicle. The data are from single or multi-layer sensors with different scopes and ranges. The sensors can operate simultaneously or individually, synchronously or not.

- Version: v1

5.4. Path2TrajectoryPlanner

Participants: Fawzi Nashashibi [correspondant], Paulo Lopes Resende.

This software can calculate the exact trajectory of a vehicle from its route decided by another decision-making system. The trajectory is expressed in terms of position and orientation and velocity versus time.

- Version: V1

5.5. SimpleController

Participants: Fawzi Nashashibi [correspondant], Paulo Lopes Resende.

This software enables the development of simple commands or controllers to be applied to drive members (actuators) of a vehicle allowing it to perform a pre-calculated trajectory. The component implements a path following controller. It takes as inputs a trajectory and a vehicle state and it determines the steering and velocity command to be performed by a car type vehicle.

- Version: V1

5.6. CCI

Participants: Fawzi Nashashibi [correspondant], Carlos Holguin.

This software provides a visual and audio interface for the users in a vehicle, in which they can select a destination and see the status of the trip and vehicle systems. It is formed by a component that runs in RTMaps that communicates through a tunnel with a C# application.

- Version: V1

6. New Results

6.1. High speed autonomous driving on roads

Participants: Fawzi Nashashibi, Laurent Bouraoui, Paulo Lopes Resende.

In this exceptional year, IMARA-INRIA had a very busy agenda with several scheduled demonstrations in the frameworks of several European projects, especially HAVEit, CityMobil and CityNetMobil.

The HAVEit project final event took place at Boras (Sweden) in June. IMARA was tightly involved in the development of the Joint Demonstrator called FASCar-II. In this demonstrator, IMARA was responsible for the development of the Co-Pilot system. This is the main decisional system that handles the manoeuvres to be executed taking into account the multisensor data fusion sub-system, the driver monitoring system and the infrastructure (data provided by the infrastructure-to-vehicle telecommunications). The system also generates the trajectories to be executed as well the control-command laws to be send to the actuators [40] and provides passive or active assistance to the driver according to the active automation level.

Figure 1. The Co-Pilot system in the Joint system architecture and HAVEit's FASCar demonstrator

In parallel, IMARA has also developed the "*Wireless Infrastructure to Vehicle communication system*". Here, a specific hardware and software systems have been developed to allow V2I and V2V applications integrated on the Joint System demonstrator. This architecture – called the 4GCube – is based on the wireless communications devices and standards (802.11 a/b/g); they are IPv6 / CALM compliant architectures that have been tested with 2.4 GHz and 5 GHz bands, allowing multiple services handling.

Figure 2. The device used for V2V and V2I wireless communications.

The integration and the validation of the Co-pilot system as well as the communication device were done during the Final Event of HAVEit with a tremendous success and with high professional standards. The FASCar was able to demonstrate high driving autonomous skills at high speeds (up to 120 km/h) and was able to demonstrate new advanced features like overtaking mobile and static obstacles.

6.2. New urban transportation platforms: INRIA's Cybus

Participants: Laurent Bouraoui, François Charlot, Carlos Holguin, Fawzi Nashashibi, Tony Noël, Michel Parent, Paulo Lopes Resende, Jianping Xie, Armand Yvet.

In order to achieve autonomous driving, autonomous systems (robots, intelligent vehicles, UAV's, UGV's,...) must have a decisional system that integrates an advanced perception system that performs sensors data fusion and environment modeling. From perception to control, task planning and path planning algorithms have to plan safe and optimized itineraries while processing sensory data. Motion control is the last link of the processing chain where itineraries and dynamic trajectories are executed by the low level control system. IMARA works on each of the topics mentioned above.

With the European projects CityMobil and CityNet Mobil, IMARA had the opportunity to validate the autonomous driving architecture developed through the projects showcases held in European cities. In 2011, several cities hosted IMARA team in charge of demonstrating autonomous driving and autonomous sensor-based navigation using sensory data (laser scanners) and GNSS (GPS). These events were a total success and were the opportunity to deploy and test the large-scale SLAMMOT system used for environment mapping, vehicle localization and mobile obstacles detection but also the new VMS (Vehicle Management System) developed in order to coordinate the mobility and navigation of several Cybercars (INRIA's Cybus platforms).

For this purpose, *the perception sub-system* was based on the generic SLAM-based system that was already presented in detail last year [43]. The proposed localization architecture has been implemented in two different vehicle platforms. AGV is a fully autonomous vehicle equipped with two IBEO Alasca-XT laser scanners (left and right front corner). Cycab is a prototype of smart car mounted with a single IBEO-ML laser scanner in front.

This year, because of delivery problems related to an industrial partner, IMARA had to design and develop its own cybercars. Thus the *Cybus* are the newest prototyping and demonstration platforms designed at INRIA. Apart from the chassis and engines, the whole hardware and software systems were developed thanks to IMARA's researchers and engineers talents. These electric vehicles are based on a Yamaha chassis but the embedded intelligence is the result of this year's IMARA developments. Much of the perception and control software is now registered.

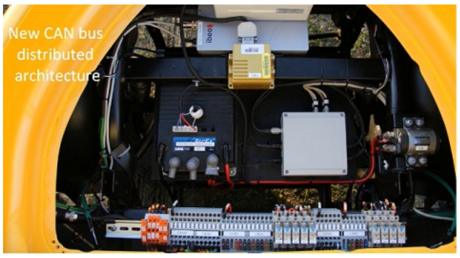

Figure 3. The Cybus hardware architecture

The system developed can be seen as an experimental platform for a new public mobility transportation system operating in mixed environments. This electric vehicle is a “clean” transportation mean that is capable to achieve the well known last-mile itinerary in urban areas where classical transportation means are inefficient or simply non profitable. In order to demonstrate the feasibility of the system, a 3-months service has been programmed in the City of La Rochelle. The Mayor of the City authorized the Cybus to operate during 3-months providing free transport service to the inhabitants of the city. For that purpose, a 2 kilometers route has been defined on which 5 calling stations where installed. The users were able to call the Cybus from any station to reach any other station. The evaluation of the system has shown an acceptability of more than 95% among population; very low failures or technical leakages were reported. Following this successful operation, the European Commission asked INRIA to extend this operation as well as its technical capabilities in order to achieve a simultaneous multiple Cybus navigation. This was achieved last December and was a real success.

Figure 4. The Cybus operated at La Rochelle City during 3 months as a free transport service.

The platforms developed here (Cybus) were exploited and demonstrated in the context of the EU-CityNetMobil project. The cities of Antibes (France) and Reggio di Calabria (Italy) hosted the team for 2 weeks respectively in order to experiment this new mobility and transportation mean in the heart of their cities.
Following this success, a new proposal of CityMobil-2 project is under submission with the objective this time to extend real operational mobility services to 6-12 months in selected European cities !

6.3. Communications Management in Cooperative Intelligent Transportation Systems

Participants: Thierry Ernst, Manabu Tsukada.

Cooperative Intelligent Transportation Systems (Cooperative ITS) are systems where the vehicles, the roadside infrastructure, central control centers and other entities exchange information in order to achieve better road safety, traffic efficiency and comfort of the road users. This exchange of information must rely on a common communication architecture. The ITS Station reference architecture has thus been specified in ISO and ETSI. It allows vehicles and roadside ITS stations to organize themselves into Vehicular Ad-hoc Network (VANET), presumably though IPv6 GeoNetworking using IEEE802.11p and to connect seamlessly to the Internet though any available access technology. Several paths may thus be available at a given vehicle ITS station to communicate with other ITS stations. Paths are of three types: direct path, optimize path and anchor path. The objective of the study is to optimize the communication between ITS Stations by selecting the best available communication path. This requires first to gather information available locally at the ITS station (position, speed, application requirements, media characteristics, capabilities, path status, ...) and collected from neighbors ITS stations (position, speed, services, ...) and then to process this information through a decision-making algorithm. First, we define a network module allowing the combination of IPv6 together with GeoNet- working. Second, we propose a cross-layer path selection management module. Our contributions are mapped to the ITS station reference architecture by defining the relation between the ITS station network and transport layer (which hosts our IPv6 GeoNetworking contribution) and the vertical ITS station cross-layer entity (which hosts the path decision-making algorithm). We specify the functions allowing the exchange of parameters through the Service Access Point (SAP) between the network layer and the management entity (MN-SAP). The parameters used at the cross layer ITS station management entity are abstracted in a way so that they are agnostic to the protocols used at the ITS station network and transport layer, therefrom allowing easy replacement of protocol elements (e.g. replacing NEMO by other mobility support protocol) or permutation of the network stack (IPv6 or GeoNetworking, a combination of both or other network stack).

6.4. Managing the system (via probabilistic modeling)

6.4.1. Belief propagation inference for traffic prediction

Participants: Cyril Furtlehner, Jean-Marc Lasgouttes, Arnaud Lewden, Victorin Martin.

This work [41] deals with real-time prediction of traffic conditions in a setting where the only available information is floating car data (FCD) sent by probe vehicles. The main focus is on finding a good way to encode some coarse information (typically whether traffic on a segment is fluid or congested), and to decode it in the form of real-time traffic reconstruction and prediction. Our approach relies in particular on the belief propagation algorithm.

These studies are done in particular in the framework of the projects TRAVESTI and Pumas.

This year's highlights are

- A particular effort has been done this year in studying the theoretical aspects of the ways to encode real valued variable into an binary Ising model. A publication on the subject is in preparation.
- A review of our work on road traffic inference using methods from statistical physics has been published [21].
- The investigation of the effect of various types of normalization in the belief propagation algorithm has lead to a technical report [38].
- Arnaud Lewden has specified and implemented the new software BPstruction, which is our contribution to the Pumas project. Besides implementing traffic reconstruction from FCD, it is intended as a testbench for our research on inference using Belief Propagation.
- Victorin Martin has given a talk at the "Séminaire de Modélisation des Réseaux de Transport" at IFSTTAR. He presented there our method for real-time traffic reconstruction and prediction.
- Jean-Marc Lasgouttes also presented this work at the Xerox Research Centre Europe seminar.

6.4.2. Evaluation of dual mode transport system by event-driven simulation

Participants: Arnaud de La Fortelle, Sami Mahari.

The European project CATS — City Alternative Transport System — is developing and evaluating a new vehicle system using a single type of vehicle for two different usages: individual use or collective transport. Real experiments will necessarily take place with a limited number of vehicles and stations. Hence there is a need for evaluation using simulations. We have been developing a discrete events simulator for that purpose, based on a previous work done for collective taxis [42].

Our model relies on an adapted events/decision graph that extends previous graphs. The new feature of this model is the way we deal with two modes that can be extended to many other modes. This work therefore shows on a concrete example a method to efficiently merge multiple modes into one model.

- This year has seen the design and first implementation of the simulator.
- The results have been presented at a conference [29].

6.4.3. Multi-speed exclusion processes

Participants: Cyril Furtlehner, Jean-Marc Lasgouttes, Maxim Samsonov.

The slow-to-start mechanism is known to play an important role in the particular shape of the Fundamental diagram of traffic and to be associated to hysteresis effects of traffic flow. We study this question in the context of stochastic processes, namely exclusion and queueing processes, by including explicitly an asymmetry between deceleration and acceleration in their formulation. Spatial condensation phenomena and metastability are observed, depending on the level of the aforementioned asymmetry. The relationship between these 2 families of models is analyzed on the ring geometry, to yield a large deviation formulation of the fundamental diagram (FD)

This work has been presented at the TGF'11 conference [22], and a more extensive article is in preparation for a journal.

6.4.4. Dynamics of points of interest in a social game

Participants: Guy Fayolle, Jean-Marc Lasgouttes.

Ma Micro Planète is a geolocalized video game which entices players to use sustainable means of transport. At the heart of the game are community-driven *points of interest* (POI's), or *sites*, which have a score that depends on the players activity. The aim of this work is to understand the dynamics of the underlying stochastic process.

We examine the system in the thermodynamic limit, as the number of players tends to infinity, the existence of which is proved under general conditions, where the probability of increasing the score of a visited POI is a function of the state of the system. Concerning the existence of a stationary regime, some complete answers are given for particular values of the parameters, and the existence of possible phase transition phenomena is enlightened.

A publication on the subject is in preparation.

6.4.5. Random walks in the quarter plane

Participant: Guy Fayolle.

In collaboration with K. Raschel (CNRS, Université F. Rabelais à Tours), we pursued the works initiated in 2010 in two main directions.

6.4.5.1. The zero drift case

In several recent studies on random walks with small jumps in the quarter plane, it has been noticed that the so-called *group of the walk* governs the behavior of a number of quantities, in particular through its *order*. In the article [11], when the *drift* of the random walk is equal to 0, we provide an effective criterion giving the order of this group. More generally, we also show that in all cases where the *genus* of the algebraic curve defined by the *kernel* is 0, the group is infinite, except precisely for the zero drift case, where finiteness is quite possible.

6.4.5.2. Counting and asymptotics

The enumeration of planar lattice walks, is a classical topic in combinatorics. For a given set $\mathcal{S}$ of allowed unit jumps (or steps), it is a matter of *counting the number of paths* starting from some point and ending at some arbitrary point in a given time, and possibly restricted to some regions of the plane.

Like in the probabilistic context, a common way of attacking these problems relies on the following analytic approach. Let $f(i,j,k)$ denote the number of paths in $\mathbb{Z}_+^2$ starting from $(0,0)$ and ending at (i,j) at time k. Then the corresponding CGF

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

satisfies the functional equation

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

where x,y,z are complex variables, although the time variable z plays somehow the role of a parameter. The question of the type of the associated counting generating functions, that is rational, algebraic, holonomic (solution of a linear differential equation with polynomial coefficients), was solved whenever the group is *finite* (see RA 2010). When the group is infinite, the problem is still largely.

It turns out that the nature of singularities play a deep important role in this classification. Making use of the general and powerful approach proposed in the book [3], a paper entitled *Some exact asymptotics in the counting of walks in the quarter-plane* has been submitted to AofA (*International Conference on Analysis of Algorithms*, Montreal, june 2012), in which a new approach is proposed to obtain some exact asymptotics for walks confined to the quarter plane.

6.4.6. Statistical physics and hydrodynamic limits

Participants: Guy Fayolle, Cyril Furtlehner.

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

To attack this class of problems, in touch with many applications domains (e.g. biology, telecommunications, transportation systems), we started from *paradigmatic* elements, namely the discrete curves subjected to stochastic deformations, as those mentioned for instance in [39]. After convenient mappings, it appears that most models can be set in terms of interacting exclusion processes, the ultimate goal being to derive *hydrodynamic limits* for these systems after proper scalings. We extend the key ideas of [39], where the basic ASEP system on the torus was the toy model. The usual sequence of empirical measures, converges in probability to a deterministic measure, which is the unique weak solution of a Cauchy problem.

The Gordian knot is the analysis of a family of specific partial differential operators in infinite dimension. Indeed, the values of functions at given points play here the role of usual variables, their number becoming infinite. The method presents some new theoretical features, involving promeasures (as introduced by Bourbaki), variational calculus, functional integration, and the construction of *generalized measures*. In [20], we present a detailed analysis of the ASEP system on the torus $\mathbb{Z}/N\mathbb{Z}$. Then we claim that most of the arguments a priori work in higher dimensions (ABC, multi-type exclusion processes, etc), leading to sytems of coupled partial differential equations of Burgers' type. In the course of the study, several fascinating multi-scale problems emerge quite naturally, bringing to light some connections with the so-called *renormalization* in theoretical physics.

7. Contracts and Grants with Industry

7.1. Contracts with Industry

This year began a true cooperation between IMARA team and the Valeo Group. A first direct contract has been signed in order to tighten our collaboration on vision and image processing technique within the AMARE project. Later on, Valeo has expressed its wish to collaborate more closely with IMARA in the domain of autonomous navigation and low speed driving in urban areas. A “Chaire” is expected to be signed between Valeo Group, INRIA and Mines ParisTech in order to formalize these collaborations.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. Co-Drive

Instrument: FUI-10

Duration: 2009-2012

Coordinator: Valeo

Abstract: the objective is to design and develop a user-end on-the-shelf product. This product will be embarked on a vehicle and is supposed to guide the driver and/or perform autonomous actions in order to optimize the driving process for enhanced mobility and security.

8.1.2. Corebots

Instrument: ANR

Duration: 2009-2012

Coordinator: Armines

Others partners: Intempora, Epitech

See also: http://corebots.net/

Abstract: The CoreBots team has been constituted to participate in the CAROTTE challenge for advanced autonomous robots organized by the French DGA and ANR. It is made of public and private entities specialized in robotics and gathers specialists of robotics hardware, software architecture and algorithms.

8.1.3. ABV

Title: Automatisation basse vitesse

Instrument: ANR

Duration: 2009-2012

Coordinator: IFFSTAR

Others partners: Continental, IBISC, IEF, Induct, LAMIH, Vismetris, UHA-MIPS, Véolia Environnement

See also: http://www.projet-abv.fr/

Abstract: This ambitious project aims at demonstrating automated driving at low speed in urban areas and on peri-urban roads...

8.1.4. PUMAS

Title: Plate-forme Urbaine de Mobilité Avancée et Soutenable

Instrument: FUI

Duration: 2010-2012

Coordinator: Egis Mobilité

Others partners: Induct, Intempora, Armines, Insa-Rouen, Esigelec

See also: http://www.projet-pumas.fr/

Abstract: The purpose of the project PUMAS is to create a platform for travel time information for cities and towns.

8.1.5. AMARE

Title: Accrochage Mécanique Automatique à Rendez-vous Électronique

Instrument: ADEME

Duration: 2009-2011

Coordinator: Modulowatt

Others partners: Valeo, Aicom, ADM Concept, Aixam Mega, DBT, Eigsi, groupe Chastagner

See also: http://www.modulowatt.com/Modulowatt_Projets.html

Abstract: AMARE is an innovative aiming at developing an original system dedicated to the automated charging of electric vehicles.

8.1.6. Travesti

Title: Traffic Volume Estimation via Space-Time Inference

Instrument: ANR SYSCOMM

Duration: 2009-2012

Coordinator: Inria (TAO)

Others partners: Armines

See also: http://travesti.gforge.inria.fr

Abstract: This project addresses the problem of modelling large scale complex systems to provide predictions of their macroscopic behaviour. For application purpose, we focus here on the particular problem of the real-time prediction of traffic conditions on a road network.

8.2. European Initiatives

8.2.1. FP7 Projects

8.2.1.1. HAVE-IT

Title: Highly Automated Vehicles for Intelligent Transport

Type: COOPERATION (ICT)

Defi: Intelligent vehicles and mobility services

Instrument: Integrated Project (IP)

Duration: February 2008 – July 2011

Coordinator: Siemens AG, Siemens VDO Automotive (Germany)

Others partners: DLR (D), VW (D), IFSTTAR (F), ICCS (GR), EPFL (CH), USTUTT (D), VTEC (S), EFKON (A), KB (H), Ibeo (D), SVF (F), UAM (D), BME (H) ...

See also: http://www.haveit-eu.org

Abstract: HAVE-IT aims at the realization of the long-term vision of highly automated driving for intelligent transport. The project will develop, validate and demonstrate important intermediate steps towards highly automated driving. The results offer a high potential for exploitation within 3-7 years after HAVE-IT. In the longer term they also form the ideal basis to integrate further next generation ADAS and drivetrain components that offer highly automated functionalities.

8.2.1.2. INTERSAFE 2

Title: Cooperative Intersection Safety

Type: COOPERATION (ICT)

Defi: ICT for cooperative Systems

Instrument: Specific Targeted Research Project (STREP)

Duration: June 2008 – May 2011

Coordinator: Ibeo Automobile Sensor GmbH (Germany)

Others partners: BMW F+T (D), IKA (D), NEC (UK), SBH (D), TRW (UK), UTCLUJ (R), VTEC (S), VIT (FL), VW (D), Ibeao (D)

See also: http://www.intersafe-2.eu

Abstract: The INTERSAFE-2 project aims to develop and demonstrate a Cooperative Intersection Safety System (CISS) that is able to significantly reduce injury and fatal accidents at intersections. The novel CISS combines warning and intervention functions demonstrated on three vehicles: two passenger cars and one heavy goods vehicle. Furthermore, a simulator is used for additional R&D. These functions are based on novel cooperative scenario interpretation and risk assessment algorithms.

8.2.1.3. ITSSv6

Title: ITSSV6 : IPv6 ITS Station Stack for Cooperative Systems FOTs

Type: COOPERATION (ICT)

Defi: IPV6 ITS Station Stack for Cooperative Systems FOTs

Instrument: Specific Targeted Research Project (STREP)

Duration: February 2011 – January 2014

Coordinator: INRIA (France)

See also: http://cordis.europa.eu/fetch?CALLER=PROJ_ICT_TEMP&ACTION=D&CAT=PROJ&RCN=98319 (temporary link)

Abstract: ITSSv6 aims at developing a reference open-source IPv6 ITS Station stack available to European and national third parties (projects, industry and academia) using IPv6 for Internet-based communications in Field Operational Tests (FOTs) of Cooperative Systems. The IPv6 networking capabilities of the ITS Station under standardization at ISO TC204 WG16 (CALM) and ETSI TC ITS are extended with additional IPv6 features required for operational deployment of Cooperative Systems i.e. enhanced performance, embedded security, remote management of deployed systems and ease of configuration. New features and their perfect integration within the ITS Station architecture (particularly ITS Station management and ITS Facilities) are specified. The project takes as an input the FP6 CVIS core communication software and additional modules developed by FP7 GeoNet. It produces an enhanced IPv6 ITS Station stack adapted to operational use in large scale FOTs to the benefit of a variety of Cooperative Systems applications which require Internet communications (road safety, traffic efficiency and infotainment types of applications).

8.2.1.4. DRIVE C2X

Title: DRIVE C2X – Accelerate cooperative mobility

Type: COOPERATION (ICT)

Defi: Driving implementation of car 2 x communication technology

Instrument: Integrated Project (IP)

Duration: March 2011 – February 2014

Coordinator: DAIMLER AG (Germany)

See also: http://www.drive-c2x.eu/project

8.2.1.5. CityNetMobil

Title: CityNetMobil

Type: CAPACITIES (TRANSPORTS)

Instrument: Coordination and Support Action (CSA)

Duration: August 2008 – July 2011

Coordinator: Centro for Transport and Logistic (CTL) – Roma (Italy)

Others partners: GEA Partners (CH), POLIS (B)

See also: http://citynetmobil.org

Abstract: Will our cities become more and more congested, polluted, and unsafe, or is there a way to reverse this trend? One new idea for urban transport is small automated low-polluting vehicles for driverless transport in cities. But can such novel systems solve mobility problems in any city? Can they be integrated into the urban structure and conventional transport networks? How would users react?

CityNetMobil is a three-year EC FP7 support action with the specific objective of helping cities answer these questions. The project began on 1 September 2008 and will run until 1 September 2011.

The project invites all interested cities to join a group of cities sharing an interest in advanced transport systems.

8.2.1.6. CityMobil

Title: Towards Advanced Road Transport For the Urban Environment

Type: IP

Instrument: COOPERATION

Duration: May 2007 – December 2011

Coordinator: TNO-Eindhoven (Netherlands)

Others partners: DLR (D), DITS (I), CRF (I), ULTra (UK), ITS Leeds (UK), EPFL (CH),...(35 partners)

See also: http://www.citymobil-project.eu

Abstract: Citymobil is a major research, development and demonstration project. it addresses the integration of automated transport systems in the urban environment. Integration based on real-life implementations of the automated transport system of 3 sites is the focus. There is a total budget of > 40 million euro.

8.2.1.7. PICAV

Title: Personal Intelligent City Accessible Vehicle System

Type: COOPERATION (TRANSPORTS)

Instrument: Specific Targeted Research Project (STREP)

Duration: August 2009 – July 2012

Coordinator: Univ. of Genoa (Italy)

Others partners: UCL (UK), UNIPI (I), MAZEL (E), ZTS VVU (SK), TCB (P)

See also: http://www.dimec.unige.it/PMAR/picav/

Abstract: PICAV is a new mobility concept for passengers ensuring accessibility for all in urban pedestrian environments. It is also a new transport system that integrates a fleet of PICAV units. Some of its features are specifically designed for people whose mobility is restricted for different reasons the main drivers of PICAV design are: ergonomics, comfort, stability, small size, mobility dexterity on-board intelligence, assisted driving, eco-sustainability, parking, vehicle/infrastructures intelligent networking. PICAV system usefully integrates the existing public transport system to make it become more accessible for older and disabled people by acting as a smooth link between walking, bicycle and conventional public transport.

8.2.1.8. CATS

Title: City Alternative Transport System

Type: COOPERATION (TRANSPORTS)

Instrument: Specific Targeted Research Project (STREP)

Duration: January 2010 – December 2013

Coordinator: Lohr Industrie (France)

Others partners: CTL (I), EPFL (CH), TECHNION (IL), GEA (CH), ERT (F), and the cities of Formello (I), Strasbourg (F), Ploiesti (R)

See also: http://www.cats-project.org

Abstract: CATS' aim is the full development and experimentation of a new urban transport service based on a new generation of vehicle. Its major innovation is the utilisation of a single type of vehicle for two different uses: individual use or semi collective transport. This new transport service is aimed at filling the gap between public mass transport and private individual vehicles.

8.2.1.9. SANDRA

Title: Seamless Aeronautical Netzorking through the integration of Data links Radios and Antennas

Type: COOPERATION (TRANSPORTS)

Instrument: Integrated Project (IP)

Duration: October 2009 – September 2013

Coordinator: Selex Communications (Italy)

Others partners: ___PARTNERS???___ Organisme, labo (pays)

See also: http://www.sandra.aero/

Abstract: The SANDRA concept consists of the integration of complex and disparate communication media into a lean and coherent architecture that provides and manages seamless service coverage across all airspace domains and all aircraft classes. The SANDRA validation activity will show the ability of the proposed integrated architecture to easily reconfigure and adapt for the flexible implementation of new communication services.

8.2.2. Major European Organizations with which Imara has followed Collaborations

University of Murcia (Spain)

After a first contact established at the Mobile IST Summit in summer 2007 with Antonio F. Gómez Skarmeta, a PhD student from University of Murcia (José Santa Lozano) was hosted by IMARA for 3 months. He studied our communication architectures and realized some performance evaluation of our communication system using our in-vehicle testbed. The evaluation tools developed during this work will be used again to evaluate forthcoming results on geographic networking.

University Carlos III of Madrid (Spain)

a new collaboration started between IMARA and the Robotics Lab of the University of Carlos III especially with the visiting Professor Jorge Villagrá. Since his research interests include nonlinear and optimal control for automotive applications, nonlinear estimation, and robust networked control systems in robotic applications, IMARA started a collaboration with him in these fields. A first result of this cooperation was the hosting by IMARA of a PhD student from this university: Joshue Perez Rastelli spent 3 months at IMARA. He studied our activities in control-command for mobile vehicles and contributed in the AMARE project. In March 2012, he will integrate IMARA in a Post-doctoral position.

University of Roma La Sapienza (Italy)

IMARA and the Centre of Transport and Logistics of the University of Rome La Sapienza have been close partners in several European projects (Cybercars, CityMobil, CityNetMobil...). We have shared interests in cybercars and in the design of new transportation models and systems in general. Early 2011, Professor Adriano Alessandrini spent 3 months at INRIA in our team. His stay was the opportunity to organize a number of events and showcases and to prepare a common proposal for a new European project that was submitted late 2011. This collaboration seem to be very fruitful for both parties from the scientific point of view. We believe this relationship will be a permanent relationship between these institutions.

Technical University of Sophia (Bulgaria)

IMARA is conducting a close partnership with the Technical University of Sophia (Department of Mechanical Engineering). Since 2009, Professor Plamen Petrov has been a visiting professor at INRIA. He contributed in conducting common advanced researches with IMARA researchers in the field of dynamic modeling and adaptive motion control for vehicles and robots. Joint works have been also driven to develop and validate platooning concepts for normal speed driving of automated vehicles. This collaboration will continue with further scientific challenges to tackle especially in the field of vehicle control and motion planning.

We also maintain longstanding bilateral relations with the following centers:

- Imperial College (E. Gelenbe);
- University of Oxford (J. Martin);
- The Institute of Communications and Computer Systems (ICCS) of the National Technical University (NTU) of Athens, Greece.

8.3. International Initiatives

8.3.1. INRIA International Partners

We are cooperating with a number of labs worldwide without contract commitment.

SwRI: in 2007, INRIA signed a collaboration agreement with the Southwest Research Institute (San Antonio, Texas, USA) for the joint development of autonomous vehicle technologies, focusing on the areas of perception, intelligence, command and control, communications, platforms and safety. SwRI is one of the oldest and largest nonprofit applied research and development organizations in the U.S. The partnership will conduct joint research and exchange intellectual property to foster rapid technology and system advancements in vehicle autonomy. In 2011, This collaboration agreement has been reconducted for four more years.

Keio University (Japan): IMARA has established links with Jun Murai Lab at Keio University in Japan since 2005, which led Thierry Ernst to join IMARA in 2006. Since then, we are working with Keio University and other labs in Japan and in France grouped into the Nautilus6 project which is working on IPv6 mobility enhanced mechanisms allowing continuous access to the Internet while on the move. From this cooperation, we were able to hire a PhD student who completed his MSc at Keio University. In addition, three labs from Keio University with different backgrounds (automatic vehicles, electric vehicles and Internet communications) have joined forces into the so-called co-Mobility project aiming at developing the vehicle of the future. The intersection between Keio University's activities on this project and IMARA is a tremendous set of common research topics and as such we have been invited to a Co-Mobility workshop in Japan in January.

University of Tokyo (Japan): During his 1-year stay within IMARA Dr. Yoshio Mita's (associate professor at Tokyo University) was successful into organizing a private workshop between University of Tokyo and IMARA. It was held in July and gathered 10 researchers from Japan. From this workshop a number of new collaboration items were identified, including on the communication research topic in which there was not previous cooperation with University of Tokyo. In 2009 and 2011, INRIA and the University of Tokyo organized two bi-national workshops at INRIA. In 2011, this workshop was held on January 6th at INRIA Rocquencourt with the participation of 25 people from both laboratories. We are likely to enforce our cooperation with University of Tokyo in the coming years.

NICTA (Australia): After first contacts established in 2007, a PhD student started his work on a join PhD program between NICTA and IMARA. This student is currently working in Australia. Our commitment on this joint PhD supervision guarantees an outstanding cooperation with NICTA. In addition to the ongoing joint PhD supervision, IMARA has welcomed an intern from NICTA who worked on security applied to ITS architecture communications.

ESPRIT (École Supérieure PRivée d'Informatique et de Technologie, Tunis, Tunisia): IMARA is welcoming interns from this private school for the past 2 years and hired them as engineers. A joint seminary, involving IMARA, HIPERCOM, ESPRIT and ENSI took place in February 2010. A wider cooperation has been decided, based on the common interest in vehicular adhoc networking and more particularly geonetworking (geographic addressing and routing). ESPRIT and IMARA started in February 2010 the development of an open-source implementation of IPv6 GeoNetworking conforming with the specification of the FP7 GeoNet project now adopted by ETSI TC ITS. This code will be published as open-source early 2011.

NAIST (Nara Institute of Sciences and Technologies – Nara – Japan): IMARA and NAIST are extending their cooperation on ITS communication architecture based on the work realised by a PhD student from NAIST who is spending more than half his PhD course at IMARA. An AYAME proposal has been submitted but this funding program has been aborted due to lack of funding on the Japanese side (JSPS). However, NAIST has secured an internal funding allowing to send interns in 2011.

We also maintain longstanding bilateral relations with the following centers:

- University of Moscow (V. Malyshev);
- University of Saint-Petersburg (R. Iasnogorodski);
- IPPI, Dobrushin's Laboratory, Academy of sciences, Moscow (A. Rybko);
- several teams in USA (Berkeley, Columbia, Monterey, AT&T);
- The Electronics and Telecommunications Research Institute, Korea;

8.3.2. Visits of International Scientists

- Professor Adriano Alessandrini (University of Rome La Sapienza, CTL Lab) visited IMARA from February to April 2011
- Professor Plamen Petrov (Technical University of Sofia, Mechanical department) visited IMARA from July to September 2011
- Dr. Joshue Perez Rastelli (University of Carlos III, Robotics Lab) visited IMARA from September to November 2011

8.3.3. Participation In International Programs

French-Asian cooperation: in the context of the Asian-French project *CityHome*, very close collaboration were driven between INRIA's IMARA and E-Motion project-teams and Asian laboratories such as: NTU (Singapore), Dept. of Computer Science and Electrical Engineering Graduate School of Science and Technology Kumamoto University (Japan), Department of Automation of the Shanghai Jiao Tong University (SJTU University, China) and the Information and Communication Engineering and the Intelligent Systems Research Center at the SungKyunKwan University (SKKU), (Korea). A new similar project has started (PAMM) announcing new visits between the partners and new collaboration around autonomous vehicles and intelligent systems.

9. Dissemination

9.1. Animation of the scientific community

- An Exploratory Seminar was held at INRIA (Rocquencourt) on December 15th in cooperation with INRIA-HIPERCOM team-project and the University of Pierre et Marie Curie (LIP6 Lab). Title: "*VANETs, platoons, and DSRC: where do we stand?*". Organizer: Gérard Le Lann.
- On September 20, a first national Stakeholder Forum on "*Cooperative ITS*" was organized by IMARA (as member of the consortium SCORE@F) at INRIA Rocquencourt. The same day a national seminar and demo day was held at INRIA Rocquencourt bringing together the partners of the national AROS project. Because of this dual presentations, a hundred participants (researchers, decision maker, national authorities representatives) were present showing the interest in these two national projects.
- This year Fawzi Nashashibi was an associate editor of a number of international IEEE conferences: ICRA, IROS, IV and ITSC. He is an IPC member of several international conferences: ICAR, IV, SCS & ISM. He is also a reviewer in a number of internal journals and conferences: IJVAS and IJVICS Journals, Revue internationale "Traitement du signal", IEEE ICRA, IEEE ITS, IEEE ITSC, IEEE IV, IEEE VTC, RFIA...
- Guy Fayolle was reviewer of the PhD thesis entitled *Current fluctuations out-of-Equilibrium*, submitted by Antoine Gerschenfeld to the Department of Statistical Physics (University Paris 6), and defended at ENS on 23 january 2012. The thesis advisor was Bernard Derrida (ENS, Department of Physics). As a reviewer for the Mathematical Reviews (MR), he was in charge of the paper MR 2724327 entitled *Théorémes limites pour des variables quasi-associées hilbertiennes*.

9.2. Teaching

Fawzi Nashashibi

Licence: "Programmation avancée", 84h, niveau (L1), Université Paris-8 Saint-Denis, France

Master: "Vision pour la robotique", 16h, 2nd year (MAREVA), Mines ParisTech, France
"Programmation C++/OpenGL", 16h, 2nd year (MAREVA), Mines ParisTech, France
"programmation avancée et inforgraphie 3D", 25h, niveau (M1), Ecole d'ingénieurs ESILV, France
"Synthèse d'images", 12h, niveau (M2), INT Sud Telecom, France.

Jean-Marc Lasgouttes

Master: "analyse de données", 59.5h, second year of Magistère de Finance (M1), University Paris 1 Panthéon Sorbonne, France

Gérard Le Lann

Master

Master: “Communications et coordination temps réel dans les réseaux véhiculaires ad hoc”, Module du cours de 5ème année "Réseaux temps réel", INSA Lyon, January 2011
“Vehicular Ad Hoc Networks” Module de Master, TELECOM Bretagne, Rennes, June 2011

PhD & HdR

PhD : Olivier Mehani, *Contributions to Mechanisms for Adaptive Use of Mobile Network Resources*, Mines ParisTech / University of New South Wales, December 2011 [9]

Manabu Tsukada, *Communications Management in Cooperative Intelligent Transportation Systems, Mines ParisTech*, December 2011 [10]

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[10] M. TSUKADA. *Communications Management in Cooperative Intelligent Transportation Systems*, Mines ParisTech, December 2011.

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[11] G. FAYOLLE, K. RASCHEL. *Random walks in the quarter plane with zero drift: an explicit criterion for the finiteness of the associated group*, in "Markov Processes and Related Fields", October 2011, vol. 17, n^{o} 4, p. 619-636, http://hal.inria.fr/inria-00572276.

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