IN PARTNERSHIP WITH:
CNRS

Institut polytechnique de Grenoble

Université Pierre Mendes-France (Grenoble)

Université Joseph Fourier (Grenoble)

Activity Report 2012

Project-Team E-MOTION

Geometry and Probability for Motion and Action

IN COLLABORATION WITH: Laboratoire d'Informatique de Grenoble (LIG)

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Robotics

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Project-Team E-MOTION

Keywords: Robotics, Risk Analysis, Human Assistance, Perception, Robot Motion

Creation of the Project-Team: February 01, 2004 .

1. Members

Research Scientists
Christian Laugier [Team Leader, Research Director (DR) Inria, HdR]
Agostino Martinelli [Research Associate (CR) Inria]
Emmanuel Mazer [Research Director (DR) CNRS, HdR]
Alejandro Dizan Vasquez Govea [Inria Starting Research Position]

Faculty Member
Anne Spalanzani [Université Pierre-Mendès-France, Grenoble. Associate Professor]

External Collaborators
Pierre Bessière [LPPA lab]
Kamel Mekhnacha [CTO at Probayes]
Christopher Tay [Engineer at Probayes]

Engineers
Amaury Nègre [Research Engineer (IR) CNRS]
Igor Paromtchik [ADT ArosDyn Inria, Principal Engineer]
Mathias Perrollaz [Expert Engineer (Toyota contract)]

PhD Students
Alessandro Renzaglia [Sfly project fellowship]
Jorge Rios-Martinez [Conacyt fellowship + Inria]
Arturo Escobedo-Cabello [Inria fellowship]
Raphael Laurent [French Minister fellowship]
Stéphanie Lefèvre [Renault Cifre fellowship]
Gabriel Synnaeve [French Minister fellowship]
Nicolas Vignard [CNAM]
Chiara Troiani [Sfly project fellowship]
Procopio Silveira-Stein [Inria fellowship for internship, co-directed phD student with Aveira University (grant from Portugal]

Post-Doctoral Fellows
Panagiotis Papadakis [Inria]
Dimitrios Kanoulas [Inria]
Qadeer Baig [Inria]

Administrative Assistant
Myriam Etienne [Secretary (SAR) Inria]

2. Overall Objectives

2.1. Introduction

Main challenge: The overall objective of the Project team *e-Motion* is to address some fundamental and open issues located at the heart of the emerging research field called "Human Centered Robotics". More precisely, our goal is to develop *Perception, Decision, and Control* algorithmic models whose characteristics fit well with the constraints of human environments; then, these models have to be embedded into *"artificial systems"* having the capability to evolve safely in human environments while having various types of interactions with human beings. Such systems have to exhibit sufficiently efficient and robust behaviors for being able to operate in *open and dynamic environments*, i.e., in partially known environments, where time, dynamics and interactions play a major role. Recent technological progress on embedded computational power, on sensor technologies, and on miniaturized mechatronic systems, make the required technological breakthroughs potentially possible (including from the scalability point of view).

Approach and research themes: Our approach for addressing the previous challenge is to combine the respective advantages of *Computational Geometry* and of *Theory of Probabilities*, while working in cooperation with neurophysiologists for the purpose of taking into account Human perception and navigation models. Two main research themes are addressed under both the algorithmic and human point of views; these research themes are respectively related to the problems of *understanding dynamic scenes in human environments* and of *navigating interactively and safely in such environments*.

- *Perception & Situation awareness in Human environments*. The main problem is to understand complex dynamic scenes involving human beings, by exploiting prior knowledge and a flow of perceptive data coming from various sensors. Our approach for solving this problem is to develop three complementary paradigms:
  - *Bayesian Perception*: How to take into account prior knowledge and uncertain sensory data in a dynamic context?
  - *Risk Assessment*: How to evaluate this collision risk (i.e., potential future collisions) from an estimate of the current state of the dynamic scene, and from the prediction of the future behaviors of the scene participants?
  - *Behavior modeling & Learning*: How to model and to learn behaviors from observations?
- *Navigation, Control, and Interaction in Human environments*. The main problem is to take safe and socially acceptable goal-oriented navigation and control decisions, by using prior knowledge about the dynamic scenario and the related social rules, and by fusing noisy sensory data in order to estimate the state parameters. Our approach for addressing this problem is to develop two complementary concepts:
  - *Human-Aware Navigation*: How to navigate safely towards a given goal in a dynamic environment populated by human beings, while taking into account human-robot interactions and while respecting social rules and human comfort ?
  - *State Estimation & Control*: How to estimate the state parameters from noisy and sometime missing sensory data ? How to control a robot or a fleet of robots for executing a task in a near optimal way ?

2.2. Highlights of the Year

Awards:
- Stéphanie Lefevre has received the Best student paper award at IEEE Intelligent Vehicle conference 2012. The research work has been done in the scope of the PhD thesis of Stéphanie Lefevre (Cooperation Renault) supervised by Christian Laugier and Javier Ibanez-Guzman. Paper reference: S. Lefevre, C. Laugier, I. Ibanez-Guzman. "Risk assessment at road intersections: Comparing Intention and Expectation", in IEEE Intelligent Vehicle Symposium, Alcalia de Henares, Spain, June 2012.

- Christian Laugier has received the IEEE/RSJ IROS Harashima Award for innovative technologies 2012 for his "contributions to embedded perception and driving decision for Intelligent Vehicles".
New major partnerships:
- The e-Motion project-team has won (in cooperation with the CNRS laboratories LAAS and ISIR) a major partnership with Taiwan in the scope of the call for “International Excellence Laboratories” (I-RiCE program) launched by the National Science Council (NSC) of Taiwan. The laboratory is hosted by the National University of Taiwan, it is supported for 5 years, and the collaborative research is focusing on Human centered Robotics.
- Establishment of a new strategic partnership focusing onto the “software / hardware integration for a robust and efficient perception in dynamic environments”. A first long term project named “Perfect” involving the CEA LETI and ST-Microelectronics has been launched in the scope of the IRT (Technological Research Institute) Nano. A more focused project involving the CEA LETI and several regional companies (Probayes, Calao, Delta Drone, ST-Ericson, Semitag) has been recently submitted.
- Toyota has renewed his long-term collaborative research agreement with the e-Motion project-team for 4 years (including a PhD grant for addressing the “Autonomous Driving" topic).

3. Application Domains

3.1. Introduction

The main applications of our research are those aiming at introducing advanced and secured robotized systems into human environments. In this context, we are focusing onto the following application domains: Future cars and transportation systems, Service and Human assistance robotics, and Potential spin-offs in some other application domains.

3.2. 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 (e.g., Darpa Urban Challenge 2007) and by the fast development of ambitious projects such as the Google’s car project. Moreover, the legal issue starts to be addressed (see for instance the recent laws in Nevada and in California authorizing autonomous vehicles on roads).

In this context, we are interested in the development of *ADAS* [1] 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).

3.3. Service, intervention, and human assistance robotics

This application domain is currently quickly emerging, and more and more industrials companies (e.g., IS-Robotics, Samsung, LG) are now commercializing service and intervention robotics products such as vacuum cleaner robots, drones for civil or military applications, entertainment robots . . .). One of the main challenges is to propose robots which are sufficiently robust and autonomous, easily usable by non-specialists, and marked at a reasonable cost. A more recent challenge for the coming decade is to develop robotized systems for assisting elderly and/or disabled people. We are strongly involved in the development of such technologies, which are clearly tightly connected to our research work on robots in human environments.

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[1] Advanced Driver Assistance Systems

3.4. Potential spin-offs in some other application domains

Our *Bayesian Programming* tools (including the functions for decision making under uncertainty) are also impacting a large spectrum of application domains such as autonomous systems, surveillance systems, preventive maintenance for large industrial plants, fraud detection, video games, etc. These application domains are covered by our start-up *Probayes*.

4. Software

4.1. PROTEUS Software

Participants: Amaury Nègre, Juan Lahera-Perez.

This toolkit offers a automatic mobile robot driver, some sensors drivers (sensors as Sick laser, GPS, motion tracker, mono or stereo camera), and a 3D Simulator.

The latest developments have been focuses on the robotics simulator. This simulator is based on the simulation and 3D rendering engine “mgEngine“ (http://mgengine.sourceforge.net/) embedded with the physics engine “bullets physics” (http://bulletphysics.org) for realistic robot dynamic simulation.

We also worked on the interface with the robotics middleware “ROS“ (http://www.ros.org) in order to offer interoperability with many robotics applications.

The simulator is now fully integrated with the robotics middleware "ROS" (http://www.ros.org) which allow interoperability with a large set of robotics applications and visualization tools.

This software is developed in C++ and the simulator operates with the Lua scripting language.

The simulation software is used in the ANR Proteus (http://www.anr-proteus.fr), as a simulation engine for the PROTEUS Toolkit.

- Version: 2.0
- APP:IDDN.FR.001.510040.000.S.P.2005.000.10000
- Programming language: C/C++, Lua

4.2. AROSDYN

Participants: Igor Paromtchik, Mathias Perrollaz, Alexandros Makris, Amaury Nègre, Christian Laugier.

ArosDyn (http://arosdyn.gforge.inria.fr/) is a system which integrates our recently developped techniques to provide a real-time collision risk estimation in a dynamic environment. The main features of this software are:

1. The design provides high maintainability, scalability and reuseness of the models and algorithms.
2. The software has a user interface (UI) which is user-friendly.
3. The software facilitates the parameter tuning of the models.
4. It uses the GPU to accelerate the computation.
5. Working together with the Hugr middleware (http://gforge.inria.fr/projects/cycabtk), it can run on our experimental vehicle in real-time.

Another important property of this software is a large part of the computation task executed on GPU. As the processing of stereo image and the computaion in the BOF can be highly parallelized, we run these tasks on the GPU to improve the time performance. The GPU calculation is based on CUDA library and is carried out in an independent thread.

Furthermore, thanks to the design of the software, we can easily add new models to it and let them work together. The fast detection and tracking algorithm (FCTA) and the Gaussian process based collision assessment algorithm are added into this framework. The sofware is implemented on the Lexus car. In 2012, a demand for deposing the GPU BOF software to the APP is in progress.

4.3. Bayesian Occupancy Filter

People involved: Kamel Mekhnacha, Tay Meng Keat Christopher, C. Laugier, M. Yguel, Pierre Bessière.
The BOF toolbox is a C++ library that implements the Bayesian Occupancy Filter. It is often used for modelling dynamic environments. It contains the relevant functions for performing bayesian filtering in grid spaces. The output from the BOF toolbox are the estimated probability distributions of each cell's occupancy and velocity. Some basic sensor models such as the laser scanner sensor model or Gaussian sensor model for gridded spaces are also included in the BOF toolbox. The sensor models and BOF mechanism in the BOF toolbox provides the necessary tools for modelling dynamic environments in most robotic applications. This toolbox is patented under two patents : "Procédé d'assistance à la conduite d'un véhicule et dispositif associé" n. 0552735 (9 september 2005) and "Procédé d'assistance à la conduite d'un véhicule et dispositif associé amélioré" n. 0552736 (9 september 2005) and commercialized by ProBayes.

- Version: 1
- Patent: 0552736 (2005), 0552735 (2005)
- Programming language: C/C++

4.4. PROBT

People involved: Juan-Manuel Ahuactzin, Kamel Mekhnacha, Pierre Bessière, Emmanuel Mazer, Manuel Yguel, Christian Laugier.
ProBT is both available as a commercial product (ProBAYES.com) and as a free library for public research and academic purposes (http://emotion.inrialpes.fr/BP/spip.php?rubrique6). Formerly known as *OPL*, *ProBT* is a C++ library for developing efficient Bayesian software. It is available for Linux, Unix, PC Windows (Visual C++), MacOS9, MacOSX and Irix systems. The ProBT library (http://www.probayes.com/) has two main components: (i) a friendly Application Program Interface (API) for building Bayesian models, and (ii) a high-performance Bayesian Inference Engine (BIE) allowing to execute all the probability calculus in exact or approximate way. *ProBT* is now commercialized by our start-up *Probayes*; it represents the main Bayesian programming tool of the *e-Motion* project-team, and it is currently used in a variety of external projects both in the academic and industrial field (e.g., for the European project BACS and for some industrial applications such as Toyota or Denso future driving assistance systems).

5. New Results

5.1. Perception and Situation Awareness in Dynamic Environments

5.1.1. Sensor Fusion for state parameters identification

Participants: Agostino Martinelli, Chiara Troiani.

5.1.1.1. Problem adressed and background

The general framework based on the new concept of continuous symmetry developed during the last two years (see [67] for a detailed description of this framework) has been extensively applied to investigate the visual inertial structure from motion problem. This problem was already considered in 2011. During 2012 more general results have been found. Special attention has been devoted to identify the conditions under which the problem has a finite number of solutions. Specifically, it has been shown that the problem can have a unique solution, two distinct solutions and infinite solutions depending on the trajectory, on the number of point-features and on their layout and on the number of camera images. The investigation has also performed in the case when the inertial data are biased, showing that, in this latter case, more images and more restrictive conditions on the trajectory are required for the problem resolvability.

5.1.1.2. Theorical results

The new results have been published on the journal of Transaction on Robotics [68], in a technical report [43] and submitted to the International Journal of Computer Vision. We have also considered the case of structured light. Specifically, we have considered a sensor assembling (from now on *aerial vehicle*) consisting of a monocular camera and inertial sensors. Additionally, a laser pointer is mounted on the aerial vehicle and it produces a laser spot. The laser spot is observed by the monocular camera and it is the unique point feature used in the proposed approach. We focus our attention to the case when the aerial vehicle moves in proximity of a planar surface and in particular when the laser spot belongs to this surface. We introduced two novel contributions. The former is the analytical derivation of all the observable modes, i.e., all the physical quantities that can be determined by only using the inertial data and the camera observations of the laser spot during a short time-interval. This derivation was based on the framework introduced in [67]. Specifically, it is shown that the observable modes are: the distance of the vehicle from the planar surface; the component of the vehicle speed, which is orthogonal to the planar surface; the relative orientation of the vehicle with respect to the planar surface; the orientation of the planar surface with respect to the gravity. The second contribution is the introduction of a simple recursive method to perform the estimation of all the aforementioned observable modes. This method is based on a local decomposition of the original system, which separates the observable modes from the rest of the system. The method has been validated by using synthetic data. Additionally, preliminary tests with real data are provided and more complete experiments are in progress. The presented approach can be integrated in the framework of autonomous take-off and landing, safe touch-down and low altitude manoeuvres even in dark or featureless environment. These results have been published in the iros conference [31]

5.1.1.3. Experimental results

In parallel to this theoretical activity an experimental activity has been carried out in order to deploy our technologies to industrial partners. To this regard, we had a collaboration with the company Delta Drone in Grenoble. In this framework we introduced a new method to localize a micro aerial vehicle (MAV) in GPS denied environments and without the usage of any known pattern. The method exploits the planar ground assumption and only uses the data provided by a monocular camera and an inertial measurement unit. It is based on a closed solution which provides the vehicle pose from a single camera image, once the roll and the pitch angles are obtained by the inertial measurements. Specifically, the vehicle position and attitude can uniquely be determined by having two point features. However, the precision is significantly improved by using three point features. The closed form solution makes the method very simple in terms of computational cost and therefore very suitable for real time implementation. Additionally, because of this closed solution, the method does not need any initialization. We have implemented this method on the platform available in our lab. This is a *Pelican* from *Ascending Technologies* equipped with an Intel Atom processor board (*1.6 GHz, 1 GB RAM*) (figure 1).

Our sensor suite consists of an Inertial Measurement Unit (*3-Axis Gyro, 3-Axis Accelerometer*) belonging to the Flight Control Unit (FCU) “AscTec Autopilot” , and a monocular camera (*Matrix Vision mvBlueFOX*, FOV: 130 deg). The camera is calibrated using the Camera Calibration Toolbox for Matlab by J.Y. Bouguet at caltech. The calibration between IMU and camera has been performed using the Inertial Measurement Unit and Camera Calibration Toolbox in [66]. The IMU provides measurements update at a rate of $100Hz$, while the camera framerate is $10Hz$. The Low Level Processor (LLP) of our Pelican is flashed with the *2012 LLP Firmware* and performs attitude data fusion and attitude control. We flashed the High Level Processor (HLP) with the asctec_hl_firmware [48]. The onboard computer runs linux 10.04 and ROS (Robot Operating System). We implemented our method using ROS as a middleware for communication and monitoring . The HLP communicates with the onboard computer through a FCU-ROS node. The communication between the camera and the onboard computer is achieved by a ROS node as well. The presented algorithms are running online and onboard at $10Hz$.

The scenario setup is shown in figure 3. Since our lab is not yet equipped with a Motion Capture System, we used an ARToolKit Marker with the only aim of having a ground truth to evaluate the performance of our approach. The estimation of the camera pose provided by the marker is not used to perform the estimation.

Figure 1. AscTec Pelican quadcopter equipped with a monocular camera.

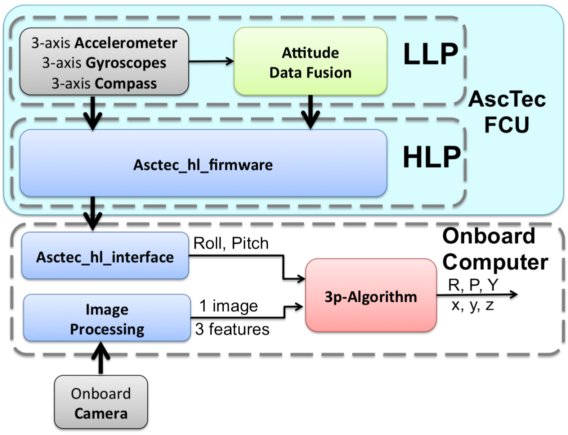


Figure 2. Our Pelican quadcopter: a system overview

The marker is positioned such that it's reference frame is coincident with the configuration shown in figure 3. The three features considered are the center of the three little balls in figure 3. The use of three blob markers instead of natural features is only related to the need to get a ground truth. The information related to the pattern composed by the 3 features ($D = 0.25m$, $\gamma_1 = 60deg$, $\gamma 2 = 120deg$) is only used to evaluate the performance of our approach. The algorithm does not require any information about the features configuration.

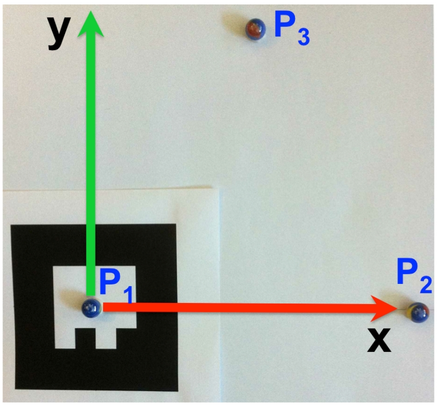


Figure 3. Scenario: The AR Marker and the 3 balls are used only with the aim to get a rough ground truth. The AR Marker provides the camera $6DOF$ pose in a global reference frame according to our conventions.

Figure 4 and 5 show respectively the position and the attitude by using the proposed approach. The estimated values are compared with the ground truth obtained with the ARToolkit marker. From figure 4 we see that the difference between our estimates and the ground truth values is of the order of $2cm$ for x and y and less than $0.5cm$ for z. From figure 5 we see that the difference between our estimates and the ground truth values is of the order of $2deg$ for $Pitch$ and less than $0.5deg$ for $Roll$ and Yaw.

We believe that the main source of error is due to the distortion of the lens, which is not fully compensated by the calibration. Note that this distortion also affects our ground truth. We plan to test our approach in an environment equipped with a Motion Capture System.

This method is currently under evaluation to be patented.

5.1.2. Visual recognition for intelligent vehicles

Participants: Alexandros Makris, Mathias Perrollaz, Christian Laugier.

We developed a generic object class recognition method. The state-of-the-art visual object class recognition systems operate with local descriptors and codebook representation of the objects. Various local features (e.g., gradient maps, edges) are used to create the descriptors. Then kernel based classifiers are commonly employed to classify the detected features in one of several object classes [50] [54]. The recognition of vehicles or pedestrians from sensors mounted on a moving platform is achieved by different approaches using various types of sensors, e.g., stereo camera, laser [61] [52]. The approaches that perform data fusion from various sensors have proven to be the more robust in a variety of road conditions [76].

Our work focuses on the development of an object class recognition system which follows the part based detection approach [65]. The system fuses intensity and depth information in a probabilistic framework. To train the system for a specific object class, a database of annotated with bounding boxes images of the class objects is required. Therefore, extending the system to recognize different object classes is straightforward. We apply our method to the problem of detecting vehicles by means of on-board sensors. Initially, depth

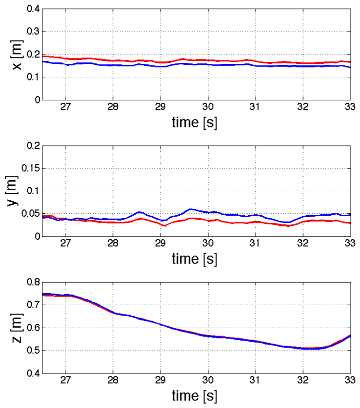


Figure 4. Estimated position, respectively x, y, z. The red lines represent the estimated values with the 3p-Algorithm, the blue ones represent a rough ground truth (from ARToolkit Marker).

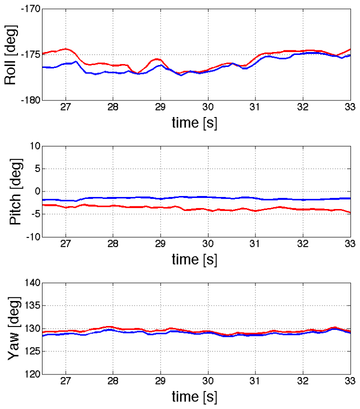


Figure 5. Estimated attitude, respectively $Roll$, $Pitch$, Yaw. The red lines represent the estimated values with the 3p-Algorithm, the blue ones represent a rough ground truth (from ARToolkit Marker).

information is used to find regions of interest. Additionally, the depth of each local feature is used to weight its contribution to the posterior of the object position in the corresponding scale. The votes are then accumulated in a 3d space-scale space and the possible detections are the local maxima in that space.

The novelty of our approach is the fusion of depth and intensity information to form a probabilistic part-based detector. Using depth information is beneficial for the robustness of the approach, because we avoid including many noisy detections resulting from false matches between features of different scales. The method is tested with stereo video sequences captured in an urban environment. Figure 6 shows some example detections. The proposed method detects cars in various scales, in cases with partial occlusions, and under significant background clutter.

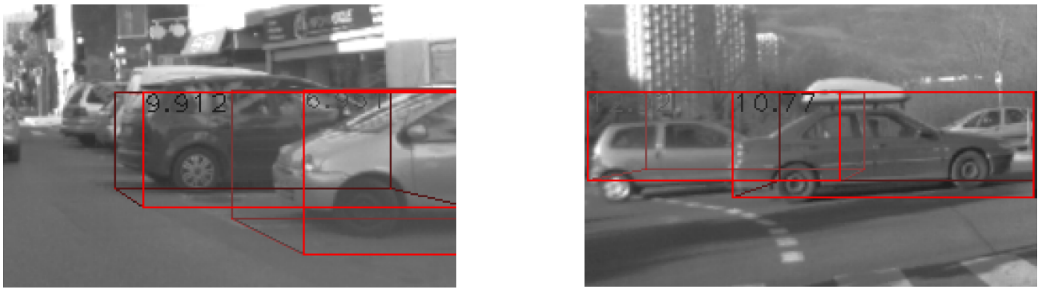


Figure 6. Car detection examples. The new weighting strategy allows to better detect the partially occulded objects.

In 2012, we worked on two particular improvements of the method. First, we modified the weighting strategy in order to increase the detection of partially occulded objects. This approach effectively improves the detection results. Second, we consider replacing the current depth descriptor, which only integrates depth information, with a more advanced depth descriptor (e.g., the NARF descriptor). This work is still in progress, in collaboration with Dimitrios Kanoulas, PhD student in Northeastern University (USA).
In 2012, the full method for objects recognition has been submitted for publication in IEEE Transactions on Intelligent Transportation Systems.

5.1.3. Bayesian Motion Detection in Dynamic Environments

Participants: Qadeer Baig, Jander Perrollaz, Mathias Botelho, Christian Laugier.

5.1.3.1. Introduction

Bayesian Occupancy Filter (BOF) [51] is a grid based perception framework that we use for environment monitoring. In this representation this framework estimates the probability of occupancy as well as velocity of each cell of this grid using sensor data. Output of this framework is used by Fast Clustering Tracking Algorithm (FCTA) [69] to cluster objects and to track them. An important point is that BOF estimates cell velocities without motion information of the ego vehicle, so these are relative velocities. Since no motion information are used, the static objects observed from the moving ego vehicle are also tracked, this results into many false moving objects. Although many of these false positives can be removed by tuning parameters of FCTA, however, this usually is a time consuming task. We note that the number of false can be reduced as well as dependence on FCTA parameters can be relaxed if we can separate the input to BOF into static and dynamic parts. Adding these motion information with cells will allow BOF to calculate velocity information for moving cells only and FCTA will also ignore the static cells while clustering step resulting into faster calculations and better track. In this context we have developed a very fast motion detection technique to separate BOF input into static and dynamic parts. The integration of this module with BOF and FCTA has helped us remove about 78% of the false positives. This technique is summarized next.

5.1.3.2. Fast Motion Detection

In this section we summarize the technique that we have developed to find moving parts of the environment. This motion detection module is situated in the processing chain just before the BOF. The input to this module consists of an occupancy grid generated by the fusion module. And the output of this module is used by both BOF and FCTA modules.

The objective of this module is to separate the input occupancy grid into two parts: cells belonging to static objects and cells belonging to moving objects. The main idea of this separation between static and dynamic parts, consists of keeping a track of how many times a cell is observed as free and how many times it is observed as moving. However to realize this concept we must solve the localization problem. We solve this problem using velocity and rotation information given by MTi-G XSens unit. This allows us to map cells between two input grids OG_{t-1} and OG_t at time $t-1$ and t as shown in figure 7.

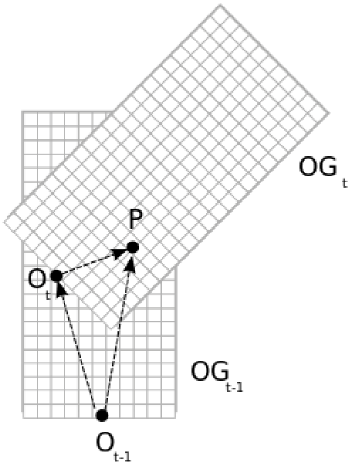


Figure 7. Position of the grid at time instants $t-1$ and t. Vehicle undergoes a motion of $u_t = (\nu_t, \omega_t)$ to move from O_{t-1} to O_t. We need to find the position of point P of grid OG_{t-1} in grid OG_t.

We use two sets of $Free$ and $Occupied$ counter arrays. One set is initialized from new input grid at time t whereas other set keeps updated counts until time $t-1$. Then after above transformation betweens cells of grids OG_{t-1} and OG_t newly initialized set of arrays is updated from arrays at time $t-1$, resulting in incremented counts for overlapping areas between two grids. Finally following decision function is used to separate cells of current input grid OG_t into static and dynamic parts and results are stored in a motion grid.

$$MotionGrid_t[i] = \begin{cases} 1, & OG_t[i] > 0.5 \text{ and} \\ & FreeCount_t[i] > 2 * OccupiedCount_t[i] \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

This technique being simple is quite robust and efficient and does not oblige us to solve the complete SLAM problem. This work is published as [19] and [20].

5.1.3.3. Integration within the BOF framework

We have updated the BOF implementation to take into account the motion detection results. The motion grid is used as an input for updating the BOF. If the input motion grid tells that a cell belongs to a static object, then during prediction and update cycles of BOF the cell's velocity distribution over the velocity range is set to uniform for all discrete velocity values. This essentially means that no velocity information for a given cell is available and the cell is labeled as static in the current BOF implementation. However, if the cell has been detected as belonging to a moving object, then the velocity distribution prediction and the update cycle are carried out normally. In formal terms this change in the parametric form of dynamic model can be stated as:

$$P(A_i^t|A_i^{t-1}) = \begin{cases} (1-\epsilon)P(A^{t-1}_{A_i^{t-1}}) + \epsilon/\|A_i\| \\ \quad \text{if } MotionGrid_t[i] > 0 \\ \\ 1/\|A_i\| \quad \text{otherwise} \end{cases}$$

where A_i^t is the set of antecedents of cell i at time t and ϵ is a parameter of BOF, modelling the prediction error probability.

5.1.3.4. Integration with FCTA

We have also updated the FCTA implementation to take into account the motion detection results. The cells which do not possess the velocity information are now ignored during the clustering step. While generally most of the areas belong to static objects and are detected as static by the motion detection module, two main advantages are expected from this strategy: (i) the clustering stage of the algorithm is highly accelerated by the reduction of hypotheses, and (ii) the false moving clusters are ignored because they are not considered for clustering, even with the relaxed FCTA parameters.

5.1.3.5. Results

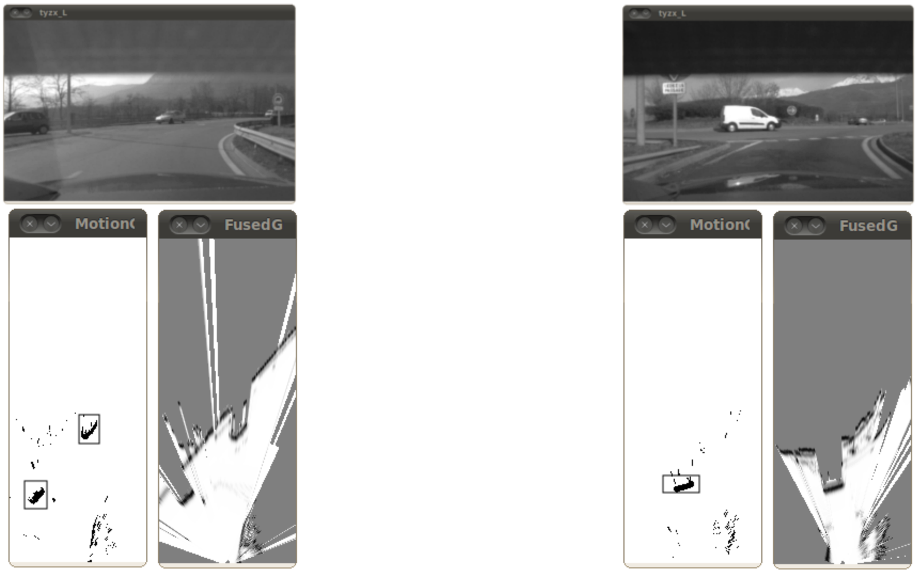
Some qualitative results of motion detection module are shown in figure 8, (rectangles around the objects are drawn manually to highlight them). As expected, the moving objects are properly detected. For example, figure 8 (left) shows the motion detection scenario of two cars, and the car moving around a roundabout has been successfully detected in figure 8 (right). Some noise is also visible on the results, mainly due to two causes: first, the uncertainty on the IMU measurements along with the circular motion model may result in some errors in the estimation of the motion; second, the decision function is too rough for taking correct decisions in every situation. The results would benefit from replacing this function by a probabilistic model.

The tracking results of FCTA are highly sensitive to its parameters values. There are less false positives when strict parameters (large thresholds) are used, however, a large number of the true tracks may be missed, resulting in numerous miss detections -note that since the focus of this work is to detect moving objects, we consider in this part that detections belonging to the static environment are false alarms-. The relaxed parameters (small thresholds) provide less miss detections, however, a large number of false tracks are detected. While finding the appropriate set of parameters can be a challenging task, our implementation of the motion detection module with relaxed parameters represents a trade-off.

The following statistics with a dataset duration of about 13 minutes give an insight into the improvements gained with this implementation. When the motion detection module is not used, 22303 tracks are detected. The activation of the motion detection module with all other parameters being equal provides to detect 4796 tracks. This example shows the advantage of the motion detection module because it allows us to remove most of the false tracks while leaving most of the true tracks. Some qualitative FCTA tracking results with and without motion detection module activated (with all other parameters being same) are shown in figures 9 and 10. Red rectangles are the detected tracks by FCTA in the shown scenario. We clearly see that most of the false positives have been removed.

5.1.3.6. Conclusion

In this section we have presented a fast technique to find moving objects from laser data and its integration with Bayesian Occupancy Filter (BOF) and Fast Clustering-Tracking Algorithm (FCTA). We have seen that after this integration we were able to remove a significant number of false alarms, this has also relaxed the dependence of results on the FCTA parameters.



a) b)//

Figure 8. Left: Motion detection results of two cars. Top, scenario, bottom right input fused grid, bottom left resulting motion grid. Right: Motion detection results of a car on a roundabout. Some noise due to sensor uncertainty is also visible

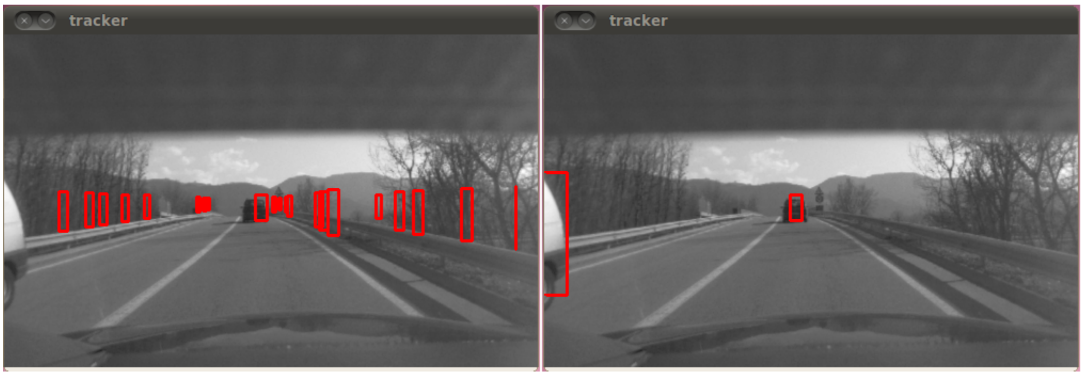


Figure 9. Tracking results of a car. Left, FCTA results without motion detection module activated. Right, same scenario but with motion detection module activated.

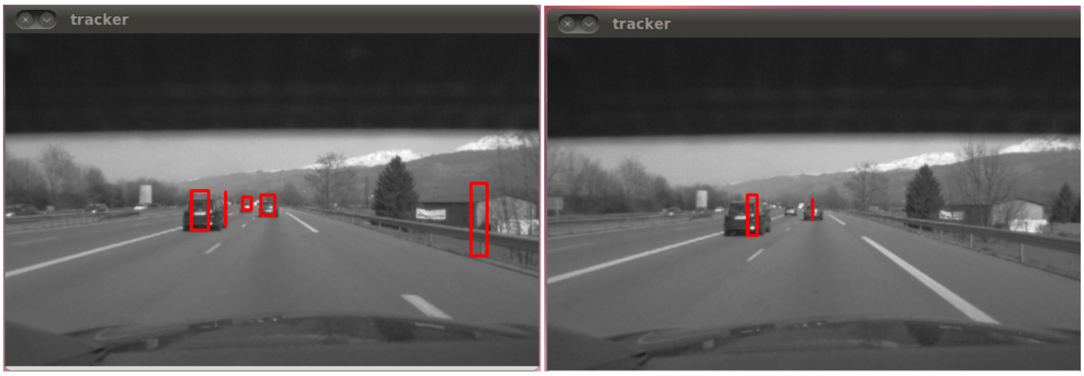


Figure 10. Tracking results of two cars on highway. Left, FCTA results without motion detection module activated. Right, same scenario but with motion detection module activated.

We plan to change the rather ad hoc decision module that is currently based on occupied and free counter values to a more formal probabilistic function that also takes into account the uncertainty effects on the neighboring cells to accommodate the localization errors. We are also working on extending the tracking module from single motion mode to multiple motion modes.

5.1.4. Vision-based Lane Tracker

Participants: Mathias Perrollaz, Amaury Nègre.

For perception in road structured environment the detection of the lane markers and its localization provide an interesting information to predict drivers behaviors and to evaluate collision risks. We currently develop a real time road lane detection and tracking application using camera's image information. The tracking application estimates simultaneously the road plane orientation, the lane curvature and the camera position by using a Monte-Carlo particle filter. With this method, the parameter distribution is represented by a set of particles (see Fig 11.a) that are sequentially updated using the vehicle dynamic model, evaluated by a ridge extraction (Fig 11.b) and sampled considering the evaluation result. The average of the particles, displayed on Fig 11.c) provides a good estimation of the lane state.

To obtain real-time performance, we implemented the whole process on GPU using the nVidia Cuda toolkit.

The output of this application has been mainly used to predict lane change behaviour 5.2.1 and to risk estimation applications.

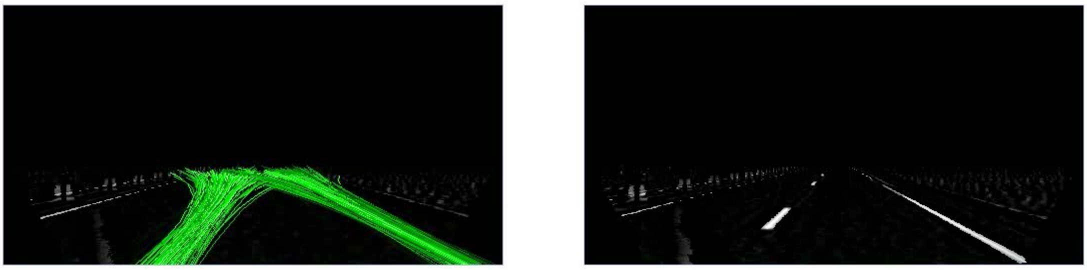
5.1.5. Experimental platform for road perception

Participants: Nicolas Vignard, Mathias Perrollaz, Amaury Nègre.

5.1.5.1. Experimental platform material description

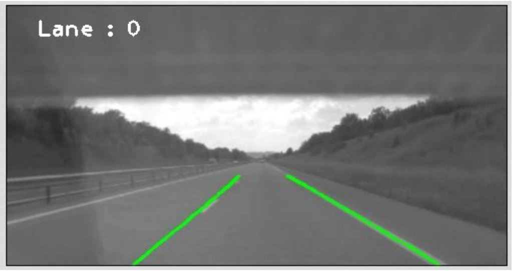
Our experimental platform is a Lexus LS600h car shown in Figure 12. The vehicle is equipped with a variety of sensors including two IBEO Lux lidars placed toward the edges of the front bumper, a TYZX stereo camera situated behind the windshield, and an Xsens MTi-G inertial sensor with GPS.

The stereo camera baseline is 22 cm, with a field of view of 62°. Camera resolution is 512x320 pixels with a focal length of 410 pixels. Each lidar provides four layers of up to 200 impacts with a sampling period of 20 ms. The angular range is 100°, and the angular resolution is 0.5°. The on-board computer is equipped with 8GB of RAM, an Intel Xeon 3.4 GHz processor and an NVIDIA GeForce GTX 480 for GPU. IMU data contains accelerations, velocity, GPS position and steering angle. The experiments are conducted in various road environements (country roads, downtown and highway), at different time of the day, with various driving



(a) Particles cloud

(b) Ridges extraction



(c) Lane state estimation

Figure 11. Visual Particle based lane tracking. (a) The Lane state is estimated by a particles set which is recursively updated, evaluated and resampled. (b) A ridge image is compute to estimate each particle. (c) The average of the particle state provides a good estimation of the lane.

Figure 12. Lexus LS600h car equipped with two IBEO Lux lidars, a TYZX stereo camera, and a n Xsens MTi-G inertial sensor with GPS.

situations (light traffic, dense traffic, traffic jams). The datasets are acquired online and are used for testing of our sensor fusion and risk assessment algorithms.

5.1.5.2. Migration from Hugr to ROS middleware

Our platform described in 5.1.5.1 previously used a middleware named Hugr. Middlewares bring an abstraction layer between the sensors drivers and the processing modules. We also used this middleware to share information with modules and applications. Using a middleware facilitates and normalises the communication between modules.

Hugr has been developed by inria for the Cycab project and a team was built to add functionalities and maintain this new middleware. However, now the team has to work on other projects and it is becoming increasingly difficult to allocate resources to maintain this middleware. Given this and some other technical issues [49], we have decided to change our robotic middlware.

We find that many different middleware (AROCAM, RTMaps, ROS,$\cdots$) are being used in the robotic community [53]. Among these, Robotic Operating System (ROS) is increasingly becoming a research standard in robotics. The reason being: an important community, a lot of tools and sharing work and development. The primary goal of ROS is to develop faster robotics applications. However, before moving to ROS we also did an extensive research on the comparison between Hugr and ROS [49], that supported our this decision.

Because of this middleware change, we had to reimplement all the perception process from drivers to applications. In this regard, we have implemented the following drivers:

- the IBEO Lux lidar
- the TYZX camera
- the CAN bus
- the Xsens MTi-G (inertial sensor with GPS)

However for the Xsens MTi-G, we found an existing driver that we modified to add the GPS functionality http://www.ros.org/wiki/lse_xsens_mti.

Furthermore, we have also migrated the following modules:

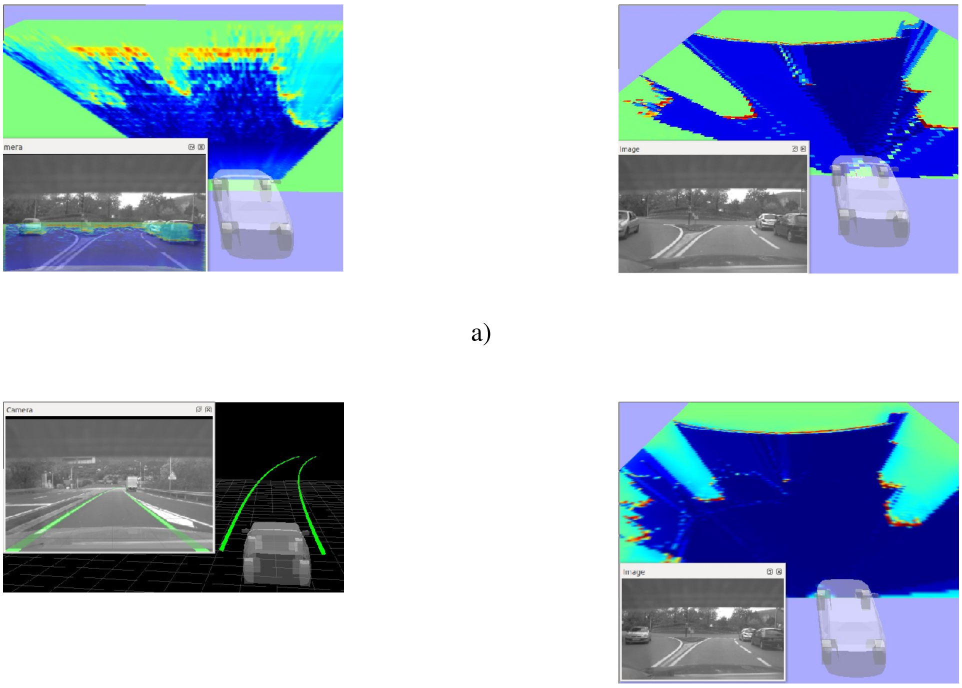
- a module that fuses lidar data into an occupancy grid
- a module that generates occupancy grid from the stereo camera
- the Bayesian Occupancy filter (BOF) module
- the lane tracker

Some result images of occupancy grids and data from the lane tracker after this migration to ROS are shown below 13. Finally, we have created a public repository at http://gforge.inria.fr that share our developments (both drivers and modules).

5.1.5.3. Disparity space approach for a vision based occupancy grid

Participants: Mathias Perrollaz, Anne Spalanzani, John-David Yoder, Amaury Nègre, Christian Laugier.

To use sensors in the BOF framework, it is essential to develop an associated probabilistic sensor model that takes into consideration the uncertainty over measurements. In 2009, we proposed such a sensor model for stereo-vision [72]. The originality of the approach relied on the decision to work in the disparity space, instead of the classical Cartesian space. In 2010, we improved our sensor model, in order to mimic some features of the sensor models used for range finders. Particularly, we worked on managing visible/occluded areas of the scene [74], and on including the information from the road/obstacle segmentation of the disparity image [73]. Our approach was also designed to allows highly parralel computation of the occupancy grid. A. Nègre implemented the approach on GPU using NVIDIA CUDA to enhance the performance. The complete processing of the stereo data can now be done in 6 ms, while more than 150 ms were necessary with the CPU implementation. The complete approach for occupancy grid computation using stereovision has been publish in 2012, in [13].



a) b)

c) d)

Figure 13. a) occupancy grid from the stereo camera. b) occupancy grid from the lidar. d) lanes detected by lane tracker. e) occupancy grid from the BOF.

5.1.6. *Software and Hardware Integration for Embedded Bayesian Perception*

Participants: Mathias Perrollaz, Christian Laugier, Qadeer Baig, Dizan Vasquez.

The objective of this recently started research work is to re-design in a highly parallel fashion our Bayesian Perception approach for dynamic environments (based on the BOF concept), in order to deeply integrate the software components into new multi-processor hardware boards. The goal is to miniaturize the software/hardware perception system (i.e., to reduce the size, the load, the energy consumption and the cost, while increasing the efficiency of the system).

This work has been started in 2012 in cooperation with CEA-LETI DACLE laboratory. During 2012, we have worked on the definition of the software/hardware architecture and we have started to re-think some components of the lower layer of the BOF software module.

The work plan has been split in two three-year-long phases, respectively leading to address a first level of integration based on mobile technologies, and a second level of integration, based on a more dedicated hardware architecture (and maybe to a SOC).

Two cooperative projects have been prepared and submitted this year for supporting this promising research: the "Permobile" project (FUI), involving industrial companies and user, and the "Perfect" project (IRT-Nano) involving the CEA-LET LIALP lab and ST-Microelectronics. Permobile is focusing on the first integration objectives (3 years) and has been recently submitted. Perfect is focusing onto the second integration objectives (6 years) and the development of integrated open platforms in the domain of transportation (vehicle and infrastructure) and in a second step in the domain of health sector (mobility of elderly and handicapped people, monitoring of elderly people at home…).

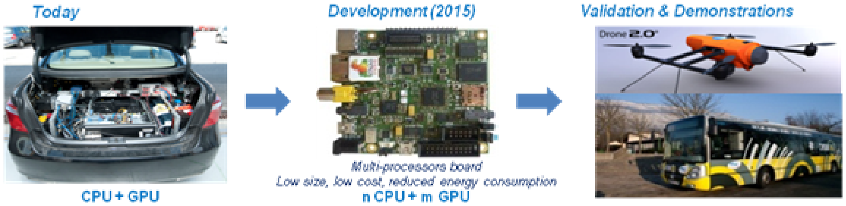


Figure 14. First objective for software/hardware of the BOF: developing and using multiple processor board from mobile technologies. The approach will be validated with real demonstrators.

5.2. Dynamic Change Prediction and Situation Awareness

5.2.1. *Vision-based Lane Change Prediction*

Participants: Puneet Kumar, Mathias Perrollaz, Stephanie Lefevre, Amaury Nègre, Maiwen Gault.

Predicting driver's behaviors is a key component for future Advanced Driver Assistance Systems (ADAS). In 2012, we have proposed a novel approach for lane change prediction, using only information from a vision sensor embedded into the car. The idea is to predict in advance if our vehicle is about to change lane. Then this information can be used to properly help the driver, for instance by detecting inconsistencies with the turn lights signals.

As an input, the method uses visual data from a camera embedded into the car. A multiple-size ridge filter is used to extract low level features from the image (white markings on black road). Then road lanes are estimated and tracked over time using a particle filter. This process allows parallel computing, and thus works in real time on GPU.

Figure 15. Vision-based tracking of the road markings. From left to right: particles generated by the particle filter, low level features extracted using the ridge filter, and estimated lane.

The road markings are used to estimate the position and heading angle of our car with respect to the lane, as well as the derivatives of these variables. This information is then used as a vector of features for a classifier. The used classifier is a multi-class Support Vector Machine (SVM). The three possible classes are "no lane change" (NL), "right lane change" (CR) and "left lane change" (CL). The classifier has been trained using real data of 180 lane changes on highway, manually annotated. The output of the classification is then converted into a set of probabilities using a generalized Bradley-Terry model.

The classifier provides a very short term classification, which can contain many errors. The longer term integration of the time information is obtained by feeding the classification results into a Bayesian Filter (BF). The posterior output of the filter provides the probability distribution over possible behaviors (NL, CR, CL), hence providing the lane change prediction.

Real-world data from our vehicle is used for the purpose of training and testing. Data from different drivers on different highways were used for the robustness evaluation of the overall approach. The proposed method show promising results, because it is able to predict driver's intention to change lane 1.3 seconds (average) in advance, with maximum prediction horizon of 3.29 seconds. We are now working on a real time implementation of this approach, to demonstrate its use on real situations (e.g., for warning the driver while driving on the highway).

5.2.2. *Risk estimation at road intersections for connected vehicle safety applications*

Participants: Stéphanie Lefèvre, Christian Laugier.

Intersections are the most complex and dangerous areas of the road network. Statistics show that most road intersection accidents are caused by driver error and that many of them could be avoided through the use of Advanced Driver Assistance Systems. In this respect, vehicular communications are a particularly promising technology. The sharing of information between vehicles over wireless links allows vehicles to perceive their environment beyond the field-of-view of their on-board sensors. Thanks to this enlarged representation of the environment in time and space, situation assessment is improved and dangerous situations can be detected earlier.

A PhD was started on this topic in 2009, in collaboration with Renault. It tackles the problem of risk estimation at road intersections from a new perspective: a Bayesian framework is proposed for reasoning about traffic situations and collision risk at a semantic level instead of at a trajectory level. While classic approaches estimate the risk of a situation by predicting the future trajectories of the vehicles and looking for intersections between them, here dangerous situations are detected by estimating the intentions of drivers and looking for conflicts between them. This novel approach to risk assessment is very relevant in the context of road traffic, as it takes into account the fact that the road network is a highly constrained environment regulated by traffic rules. The proposed approach relies on the estimation of drivers' intentions, and the main difficulty lies in the presence of uncertainties in the estimation process: uncertainties inherent to sensor data, and ambiguities when linking vehicle behavior with driver intention. In this work the information about the state of other vehicles is obtained via vehicle-to-vehicle communication, but the proposed framework for reasoning on traffic situations and risk is general and can be applied with other types of sensors, e.g., the ones presented in 5.1.3.

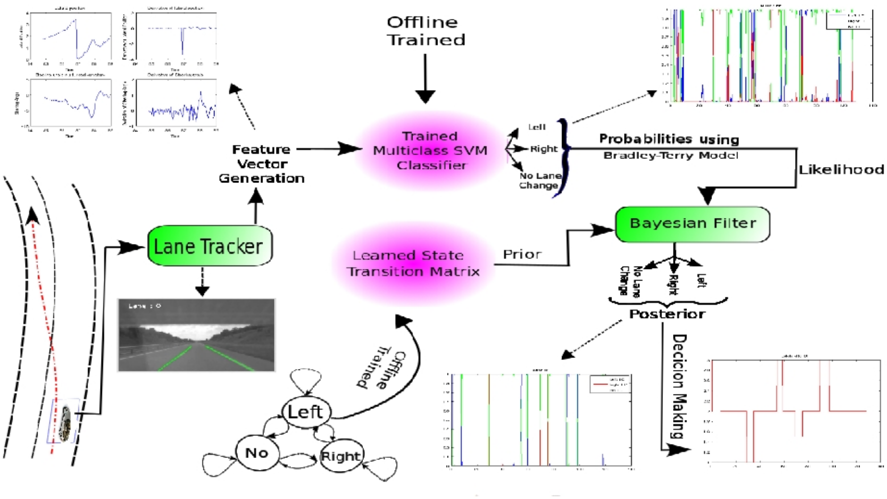


Figure 16. General architecture of the lane change prediction module.

The focus of the first year (2010) was on estimating a driver's intended maneuver at an intersection (go straight, turn left, etc.) based on the current state of the vehicle (position, orientation, turn signal state) and on contextual information extracted from the digital map. The idea was to use the information on the geometry of the road network and on the connectivity between lanes to build a statistical model of the relationship between a vehicle's state and the driver's intended maneuver. The proposed solution is based on a Bayesian Network and on geometric functions which automatically extract the characteristics of the intersection from a digital map. This approach was designed and implemented during a 3-month internship in the Stanford Artificial Intelligence Laboratory, in collaboration with Sebastian Thrun's Driving Group.

During the second year (2011) we augmented the Bayesian Network with a filtering process so that new measurements could be recursively used to estimate the driver's intentions. The new version of the motion model explicitly models the influence of traffic rules on the behavior of a vehicle. While state-of-the-art approaches usually assume independence between vehicles, the proposed motion model takes into account the mutual influences between the maneuvers performed by the vehicles in the scene. These improvements were carried out by introducing two new variables in the Bayesian Network. The ***"Intention to stop"*** corresponds to the driver's intention to come to a halt at the intersection. The ***"Expectation to stop"*** corresponds to whether or not the traffic rules expect the driver to come to a halt at the intersection. The former is assumed to be dependent on the previous intention of the driver and on the current expectation. The latter is assumed to be dependent on the rules applying at the intersection and on the previous situational context, i.e., the state of the other vehicles in the scene. With this model it is possible to infer what a driver intends to do and what a driver is expected to do from the successive measurements of the pose, speed, and turn signals of the vehicles in the scene. Risk can then be computed based on the probability that intention and expectation do not match.

The focus of this year (2012) was on the evaluation of the performance of the algorithm. The proposed approach was validated in field trials using passenger vehicles equipped with vehicle-to-vehicle wireless communication modems, and in simulation. Our simulations assumed ideal perception and communication, and considered typical accident scenarios at a two-way-stop cross intersection. The tested maneuvers included crossing maneuvers, merging maneuvers, and left turn across path maneuvers (see Figure 17). A total of 240 instances of these scenarios were simulated, with both priority violations and stop violations as accident causes. The same number of instances were simulated for non-dangerous situations, by enforcing a 3 seconds

safety distance between the vehicles at all times. An analysis of the collision prediction horizon led to the following conclusions:
1. There were no false alarms in non-dangerous situations, and no missed detection in the dangerous scenarios.
2. For merging and crossing maneuvers, the proposed algorithm was able to predict collisions at least 1.5 s before they occurred.
3. For left turn across path maneuvers, the proposed algorithm was able to predict collisions at least 0.6 s before they occurred.
4. Accidents caused by stop violations were detected on average 1 s earlier than the ones caused by priority violations.
Different accident avoidance strategies were tested: warning the driver of the vehicle with right-of-way, warning the driver of the other vehicle, applying autonomous braking on the vehicle with right-of-way, and applying autonomous braking on the other vehicle. It was found that the ability of each strategy to avoid an accident varies a lot with the situation. For example, the "autonomous braking on the vehicle with right-of-way" can avoid the accident in 91% of cases for stop violations, but only in 34% of cases for priority violations. "Warning the driver of the vehicle with right-of-way" can avoid the accident in 1% of cases for priority violations, while for the same scenarios "autonomous braking on the other vehicle" can avoid the accident in 99% of cases. These results were published at the conference IEEE IROS'12 [22], and as an Inria Research Report [41]. Field trials were conducted using two vehicles equipped with off-the-shelf vehicle-to-vehicle wireless communication modems. Six different drivers took part in the experiments to recreate realistic dangerous and non-dangerous situations at a T-shaped give-way intersection (see Figure 17). The risk estimation algorithm was run online in one of the vehicles, and triggered a warning for the driver when it detected a dangerous situation (see Figure 18). In the 120 tests, there were no false alarms and no missed detections. The warning was always triggered early enough that accidents were avoided by performing an emergency braking. The field trials proved that the proposed approach can operate with success in real-life situations and trigger warnings in real time. They also showed the robustness of the algorithm, since the experiments were carried out with several drivers, a positioning system with a precision of 2 meters (standard deviation) and challenging wireless communication conditions. These results were published at the conference IEEE IV'12 [23], where the paper received the Best PhD Student Paper award.

The PhD was successfully defended in October 2012 [9]. A patent application was filed with Renault in October 2012 [45]. This work will be continued within the Inria@SiliconValley program, in collaboration with the University of Berkeley, California. Ms Lefevre will conduct further research on this topic as a post-doctoral researcher at Berkeley starting January 2013.

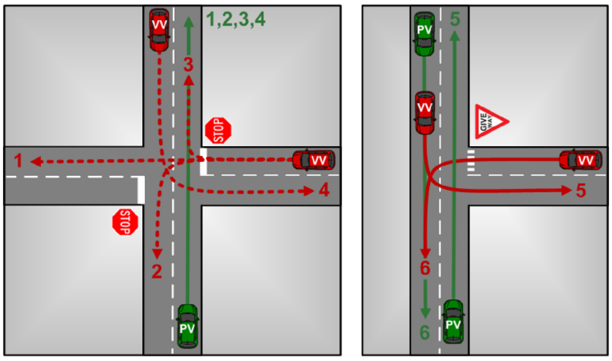


Figure 17. Scenarios tested in simulation (left) and during field trials (right).

Figure 18. Online execution of the algorithm during the field trials: warning the driver of an upcoming collision with a vehicle on the left.

5.2.3. Guidance for Uncertain shooting domain

Participant: Emmanuel Mazer.

This study is made in collabortion with MBDA (Monsieur Le Menec) and Probayes (Monsieur Laurent Saroul) under the ITP framework financed by the british MOD and the french DGA

Contex This project relates to the use of lock after launch missiles, both long range anti aircraft missiles such as Meteor, or air to ground strike weapons employing for example IIR or Semi Active Laser (SAL) guidance. In both cases, a target is ultimately recognized and tracked by means of a seeker which detects a characteristic signal above the noise. This could be the target reflections of a radar beam, or the spot from a designating laser.

However, a missile is often launched at a target range which is greater than its seeker acquisition range, although within the kinematics No Escape Zone (NEZ). It is provided with targeting geometry before launch, and maybe (via a data link) during the first part of the trajectory. However, it must fly for some period in inertial mode, and during this time the target may manoeuvre. Also, errors build up due to the imperfections in the inertial navigation system. This means that the target bearing becomes increasingly uncertain whilst the range reduces. It may be necessary to scan the seeker to acquire the target. If the scan is not matched to the possible manoeuvres, the target may escape detection. But if the scan is large, the acquisition range will be reduced, because of the reduction in search time per solid angle. As the target is acquired later, the missile's terminal manoeuvre will be more severe, and as a result the range assumed for the original kinematics NEZ may have been too optimistic. Equivalently, it is possible to be too pessimistic about the target uncertainty, hence to scan too much, and acquire the target so late that there is no longer the manoeuvre capability to reach it. Present Weapon systems optimize the probability of successful interception assuming either Gaussian uncertainties, or worst case uncertainties.

Objectives and achievments of the GUS-D system

These considerations lead to the concept of a stochastic approach for computing a probabilistic, adaptive NEZ. Probabilistic NEZ depend on the uncertain target behaviour. The uncertainties we propose to deal with are also related to the missile Inertial Navigation System (INS) precision, to sensor errors and to misalignments. Moreover, the uplink management, i.e., when to evade and breakdown the link between the launching platform and the in-flight missile plays a major role on the target localization accuracy and by the way to the size of the NEZ. Finally, there is uncertainty in the target radar cross section, which has a big effect on the seeker acquisition range. The purpose of this study is better tactical advice to the pilot about launching decision and how long maintain the uplink, and where appropriate, better matching of seeker scan strategies to target behaviours. These decisions have impacts on the probability of combat success; i.e., not only to hit the target but also on the probability to survive, as the opponent aircraft or ground threat may launch similar weapons.

The project focuses predominantly on Air to Air systems. The Meteor scan strategy has been studied deeply and is no longer critical for the engagement of fighter jets, but an objective of the study is to extend the strategy to the engagement of targets of much lower radar cross section, where the acquisition range is significantly shorter. Nevertheless all the issues apply also to Air to Ground weapon systems.

The GUS-D system is limited to one to one engagement scenario:

- one aircraft and its missile
- opponent aircraft and its missile

The main functionality of the GUS-D system is then to provide to the user a probability of successful target interception given the current engagement conditions, and the uncertainties on the target properties and behaviours.

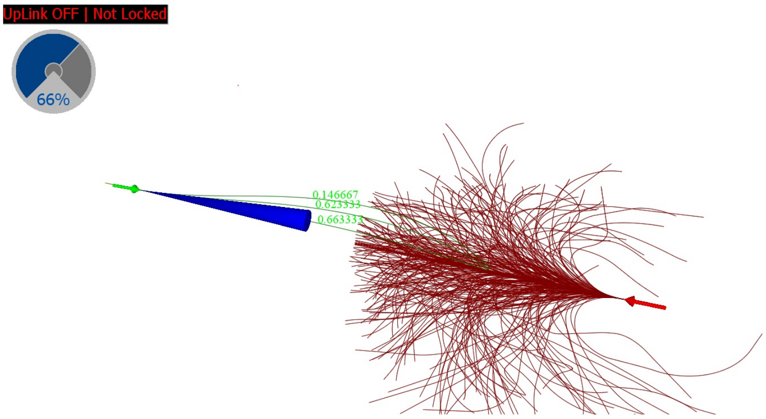


Figure 19. This Figure shows (up left corner) the "probability meter" which indicates the probability to intercept the target if the uplink is to be shutoff now. The 3D representation of the scene is displayed. The red filaments are future possible trajectories obtained with a Markov Process (MBD-UK). The blue cone modelizes the detection cone of the seeker. The green numbers indicates the probabilities to lock the target with the corresponding trajectory.

5.3. Human Centered Navigation in the physical world

5.3.1. Goal oriented risk based navigation in dynamic uncertain environment

Participants: Anne Spalanzani, Jorge Rios-Martinez, Arturo Escobedo-Cabello, Procopio Silveira-Stein, Alejandro Dizan Vasquez Govea, Christian Laugier.

Navigation in large dynamic spaces has been adressed often using deterministic representations, fast updating and reactive avoidance strategies. However, probabilistic representations are much more informative and their use in mapping and prediction methods improves the quality of obtained results. Since 2008 we have proposed a new concept to integrate a probabilistic collision risk function linking planning and navigation methods with the perception and the prediction of the dynamic environments [57]. Moving obstacles are supposed to move along typical motion patterns represented by Gaussian Processes or Growing HMM. The likelihood of the obstacles' future trajectory and the probability of occupation are used to compute the risk of collision. The proposed planning algorithm, call RiskRRT (see Figure20 for an illustration), is a sampling-based partial planner guided by the risk of collision. Results concerning this work were published in [58] [59] [60]. In 2012, We continue to work on developing probabilistic models and algorithms to analyze and learn human motion patterns from sensor data (e.g., tracker output) in order to perform inference, such as predicting the future state of people or classifying their activities. Our work has been published in the Handbook of Intelligent Vehicles [40]. We obtained some preliminary results on our robotic wheelchair combining RiskRRT with some social conventions described in section 5.3.2. This approach and experimental results have been published at ISER 2012 [32].

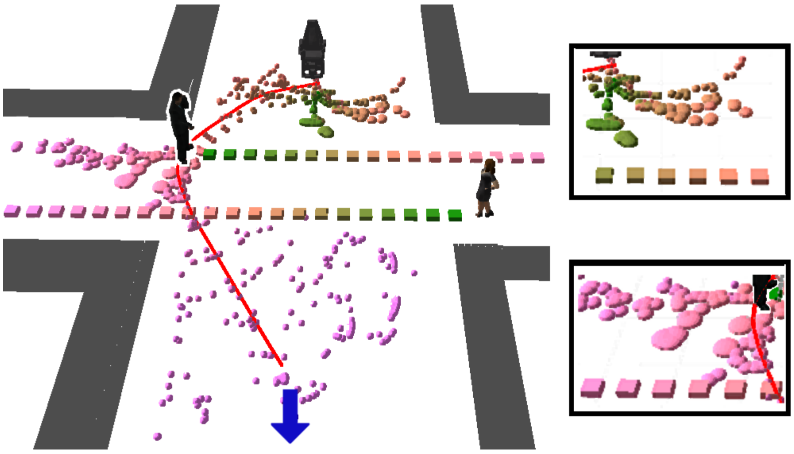


Figure 20. Predictive navigation example. RiskRRT selected a plan (red line) to the goal (blue arrow). The chosen path leads the robot to pass by the back of the first person, and then reduces the speed to let the second person to pass as well. With this strategy, the robot minimizes the risk of collision and the discomfort caused for the two pedestrians. Once second person has passed, the algorithm choses a straighter path to the goal. Frames at the right of the figure show that estimated risk is bigger at future positions of the wheelchair (circles) which are close to predicted positions of pedestrians (squares).

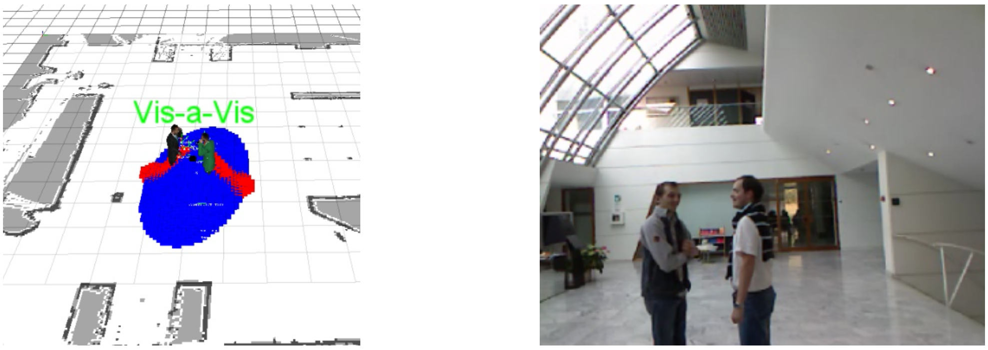
This algorithms is used in the work presented in the next three sections, work conducted under the large scale initative project PAL.

5.3.2. *Socially-aware navigation*

Participants: Jorge Rios-Martinez, Anne Spalanzani, Alessandro Renzaglia, Agostino Martinelli, Christian Laugier.

Our proposal to endow robots with the ability of socially-aware navigation is the Social Filter, which implements constraints inspired by social conventions in order to evaluate the risk of disturbance represented by a navigation decision.
The Social Filter receives from the perception system a list of tracked humans and a list of interesting objects in the environment. The interesting objects are designated manually according to their importance in a particular context, for example, an information screen in a bus station. After the process of such data, the Social Filter is able to output the risk of disturbance relative to people and interesting objects, on request of the planner and the decisional system. Thus, the original navigation solutions are "filtered" according to the social conventions taken into account. Notice that the concept of social filter is built as a higher layer above the original safety strategy, the planner and the decisional system are responsible to include the new constraints.

The on-board Kinect attached to our robotic platform was used to track people and to detect interactions. The Kinect sensor permits to get the position and orientation of the torso for each identified human. That information is passed to the Social Filter. Result images can be seen in Figure 21.



(a) (b)

Figure 21. Interaction detected with Social Filter from Kinect input for a pair of humans. Torso direction is used to estimate the main focus of interest.

In the context of socially-aware robot navigation in dynamic environments, as part of Jorge Rios-Martinez PhD thesis (to be defended in january 2013), two techniques have been proposed: one considering optimization-based navigation presented in [26] and the other a Risk-based navigation approach, previously presented in [75].

The **optimization-based navigation strategy**, done in collaboration with A. Renzaglia, is based on the Cognitive-based Adaptive Optimization (CAO) approach applied to robots [10]. We formulate the problem of socially-aware robot navigation as an optimization problem where the objective function includes, in addition to the distance to goal, information about comfort of present humans. CAO is able to efficiently handle optimization problems for which an analytical form of the function to be optimized is unknown, but the function is available for measurements at each iteration. A model of social space, contained in the Social Filter module, was integrated in order to work as a "virtual" sensor providing comfort measures. Figure22 a) shows an image of the method implementation on ROS [2] framework.

Social Filter models of social conventions were combined with RiskRRT [56] by including the knowledge of human management of space (Personal Space, interaction space, activity Space). The particular considered interaction was the conversation between pedestrians which was missed in the most part of related works. The approach presented shows a way to take into account social conventions in navigation strategies providing the robot with the ability to respect the social spaces in its environment when moving safely towards a given goal. Due to the inclusion of our social models, the risk calculated for every partial path produced by RiskRRT algorithm is given by the risk of collision along the path and the risk of disturbance to human spaces.

One last work was presented in [25], where the socially-aware navigation based on risk was integrated with a model of human intention estimation (presented in section 5.3.4. Results exhibited emerging behavior showing a robotic wheelchair interpreting facial gesture commands, estimating the intended goal and autonomously taking the user to his/her desired goal, respecting social conventions during its navigation.

5.3.3. *Navigation Taking Advantage of Moving Agents*

Participants: Procopio Silveira-Stein, Anne Spalanzani, Christian Laugier.

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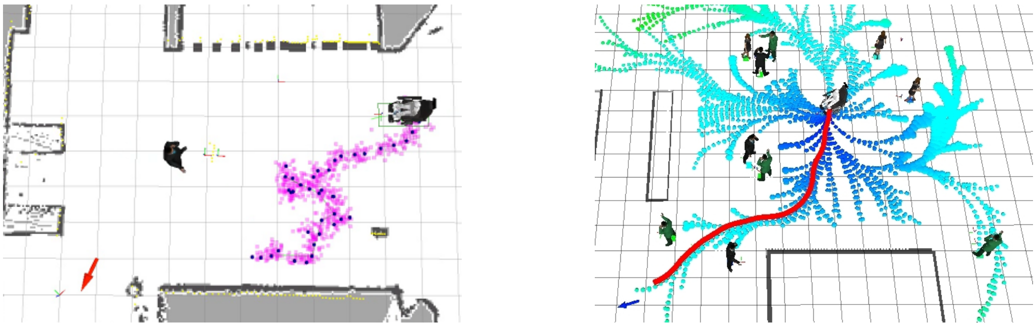
[2] http://www.ros.org



(a) (b)

Figure 22. Results of socially-aware navigation approaches. In a) the optimization-based navigation solution avoids a region were the discomfort for the human would be higher. In b) the Risk-Based navigation technique explores the space and decides to follow a path avoiding social spaces minimizing the risk of disturbance. The goal in each case is signaled by an arrow.

Following a leader in populated environments is a form of taking advantage of the motion of the others. A human can detect cues from other humans and smartly decide in which side to pass. Humans can also easily predict the motion of the others, changing his/her path to accommodate for conflictive situations, for example. Imitating the motion of a human can also improve the social acceptance of robots and so on.

The best leader is the one whose goal is close to the robot's one. To implement that, the Growing Hidden Markov Model (GHMM) technique is used [79]. This technique provides at the same time a capability to learn and modeling typical paths, as well as learning and predicting goals associated to paths, making it ideal for the proposed approach of leader election.

Once a leader is chosen, the robot starts to track his/her path and follow it, using the RiskRRT algorithm presented in section 5.3.1. This algorithm takes into account the risk of collision with other agents, guaranteeing that the robot can avoid collisions even if its leader is lost or occluded.

Some results can be seen in the following experiments, where real human data was used together with a robot simulator.

In Figure 23, the experiment demonstrates one of the advantages of following a leader to improve the robot's navigation capabilities. The direct path to the robot's goal is obstructed by two incoming humans. Normally an algorithm suited for dynamic environment would create a detour as future humans' position would conflict with the robot straight trajectory. However, as the robot is following a leader, it does not reason about the other agent's future position. Therefore, the leader knows that people will give room for he/she to pass, and the robot profits from it.

Next step will be to use this technics will navigating in a crowd, task that a common planning strategy could hardly do.

5.3.4. Autonomous Wheelchair for Elders Assistance

Participants: Arturo Escobedo-Cabello, Gregoire Vignon, Anne Spalanzani, Christian Laugier.

The aging of world's population is bringing the need to provide robotic platforms capable to assist elder people to move [77]. It is necessary that such transportation is reliable, safe and comfortable. People with motor disabilities and elders are expected to benefit from new developments in the field of autonomous navigation robotics. Autonomously driven wheelchairs are a real need for those patients who lack the strength or skills to drive a normal electric wheelchair. The services provided by this kind of robots can also be used to provide a

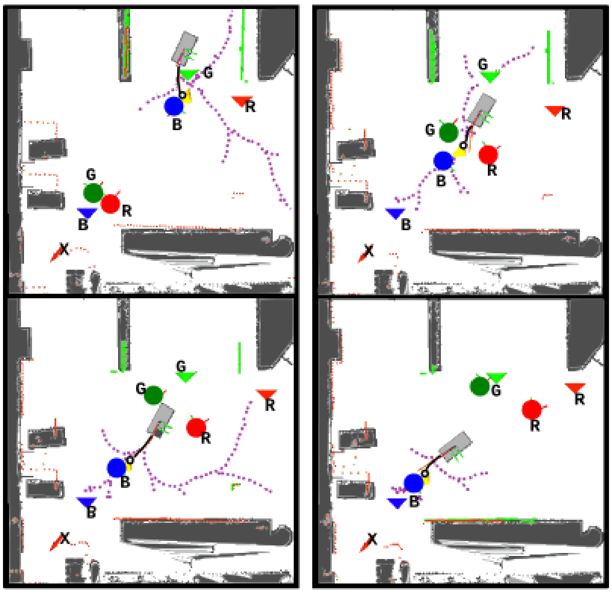


Figure 23. Robot navigation following a leader seamlessly avoid other incoming agents.

service of comfort, assisting the user to perform difficult tasks as traversing a door, driving in a narrow corridor etc. Simple improvements of the classical powered wheelchair can often diminish several difficulties while driving. This idea of comfort has emerged as a design goal in autonomous navigation systems, designers are becoming more aware of the importance of the user when scheming solution algorithms. This is particularly important when designing services or devices intended to assist people with some disability.

In order for the robot to have a correct understanding of the intention of the user (when moving around) it is necessary to create a model of the user that takes into account his habits, type of disability and environmental information. The ongoing research project is centered in the understanding of the intentions of the user while driving an autonomous wheelchair, so that we can use this information to make this task easier.

In 2011 a robotic wheelchair was set up as experimental platform. Some basic functions were included as the mapping of the environment using a Rao-Blackwellized Particle Filter [62], localization using an Adaptive Monte Carlo Localization approach (AMCL) [78], global planning using an A* algorithm [63] and local reactive planning using the Dynamic Window Algorithm [55]. Alongside some work was done with the kinect sensor in order to detect and track people. This behaviour was aimed to bring assistance not only to the user but also to the caregiver by allowing him to move more freely. The software implementation of the related approaches was done on the basis of the ROS middleware.

During 2012 the work was centered in the improvement of the usability of the system around three main axes:

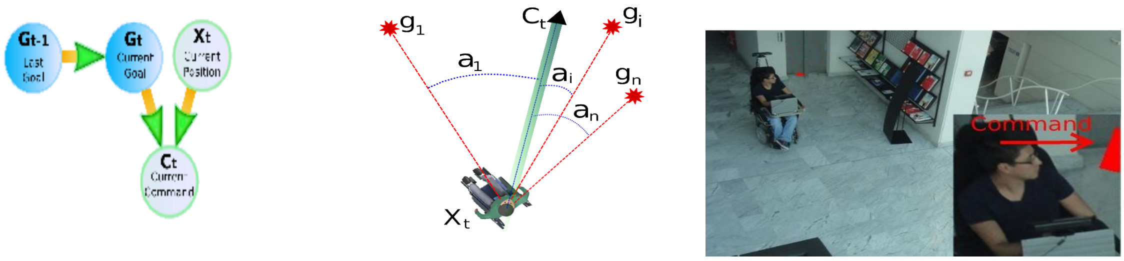
- User intention estimation: A review of the state of the art in user's intention estimation algorithms was made and a new model to infer the intentions of the user in a known environment was presented [46],[47]. The algorithm models the intention of the user as 2D topological goals in the environment. Those places are selected according to how frequently they are visited by the user (user habits). The system was designed so that the user can give orders to the wheelchair by using any type of interface, as long as he can show the direction of the intended movement (joystick, head tracking, brain control, etc). As shown ni figure24, the chosen approach uses a Bayesian model to model and infer the intentions. The main contribution of this work is to model the intention of the user as topological goals instead of normal trajectory-based methods, therefore the model is simpler to deal with. Current research is being done to understand which information is important to take into account in order to do better estimations of the user's intention. In particular, the movements of the head are considered by the proposed inference method.

The navigation is performed using the human-aware planning algorithm developed by the team which integrates a notion of social conventions and avoidance of dynamic obstacles to prevent uncomfortable situations when the wheelchair is navigating among humans (see section 5.3.2 for details)

- Interfaces: People with motor disabilities and elders often have problems using joysticks and other standard control devices. Under this consideration our experimental platform was equipped with different types of user-interfaces to provide a multimodal functionality as described in [47]. A face pose interface allows to control the wheelchair's motion by changing the face direction, while voice recognition interface is used to guarantee an adequate control of the wheelchair for those commands that otherwise would be difficult to give by only using the face (Stop, start, etc). The use of a touch screen control is also possible.
- Multimodal control: The wheelchair can be controlled in semi-autonomous mode employing the user's intention estimation module, described later, or in manual mode in which the user is in charge of driving by him self.

  In manual mode the user controls the wheelchair's angular speed moving her head while the linear speed is controlled with vocal commands (faster, slower, break, etc).

  In semi-autonomous mode the user shows the direction to his/her desired destination facing towards it. Whenever a new command is read from the face pose estimation system. The user's intention module computes the goal with the highest posterior probability. The navigation module receives the map of the environment, the list of humans present in the scene and the currently estimated goal to compute the necessary trajectory to the goal.



(a) (b) (c)

*Figure 24. **left**:User's intention model. The Bayesian network used to estimate the current user's intended goal G_t, The current position X_t and the user command C_t are used as evidence. G_t is dependent on the value of the last estimation G_{t-1}. **center**: Experimental evaluation of the user's intention module. The probability value for a given command C_t (big arrow) is proportional to the angle a_i formed respect to each goal g_i in the environment. **right:** The user is looking to the left (in the direction of his desired goal). Once that the user's intention estimation system computes the goal with the highest probability, the autonomous navigation module plans the path and controls the movement of the wheelchair to take the user to the destination.*

5.3.5. Multi-Robot Distributed Control under Environmental Constraints

Participants: Agostino Martinelli, Alessandro Renzaglia.

This research is the follow-up of a study begun three years ago in the framework of the European project sFly. The problem addressed is the deployment of a team of flying robots to perform surveillance coverage mission over an *unknown* terrain of complex and non-convex morphology. In such a mission, the robots attempt to maximize the part of the terrain that is visible while keeping the distance between each point in the terrain and the closest team member as small as possible. A trade-off between these two objectives should be fulfilled given the physical constraints and limitations imposed at the particular application. As the terrain's morphology is unknown and it can be quite complex and non-convex, standard algorithms are not applicable to the particular problem treated in this paper. To overcome this, a new approach based on the Cognitive-based Adaptive Optimization (CAO) algorithm is proposed and evaluated. A fundamental property of this approach is that it shares the same convergence characteristics as those of constrained gradient-descent algorithms (which require perfect knowledge of the terrain's morphology and optimize surveillance coverage subject to the constraints the team has to satisfy). Rigorous mathematical arguments and extensive simulations establish that the proposed approach provides a scalable and efficient methodology that incorporates any particular physical constraints and limitations able to navigate the robots to an arrangement that (locally) optimizes surveillance coverage.

Special focus has been devoted to adapt this general approach in order to deal with real scenarios. Specifically, this has been carried out by working in collaboration with the ETHZ (Zurich). To this regard, the approach has been adopted in the framework of the final demo of the sFly project. The demo simulates a search and rescue operation in an outdoor GPS-denied disaster scenario. No laser, no GPS, and Vicon or other external cameras are used for navigation and mapping, but just onboard cameras and IMUs. All the processing runs onboard, on a Core2Duo processing unit. The mission consists of first collecting images for creating a common global map of the working area with 3 helicopters, then engaging positions for an optimal surveillance coverage of the area, and finally detecting the transmitter positions.

The results of this research have been published in two journals, [14], [15], and on the thesis of A. Renzaglia, [10].

5.4. Bayesian Modelling of Sensorimotor Systems and Behaviors

Results described in this section were done in collaboration with the LPPA collège de France.

5.4.1. Bayesian based decision making in multi-player video games

Participants: Gabriel Synnaeve, Pierre Bessière.

The problem addressed in this work is the autonomous replacement of a human player. It is the continuation of last year's work on the same topic as well as a follow-up of previous E-Motion Ph.D Ronan Le Hy [64]. This year, we focused on real-time strategy (RTS) games, in which the players have to build an economy, advance technology, produce and control an army to kill the opponents. From a research point of view, multi-player games are interesting because they stand for a good in-between of the real world and simulations. The world is finite and simulated (no sensors problems) but we didn't wrote the simulation and the other players are humans (or advanced robots in the case of AI competitions).

This year's research work focused on tactical prediction and decision-making as well as armies composition adaptation. For the tactical model, the idea is to have (most probably biased) lower-level heuristics from units observations, which produce information exploitable at the tactical level, and take advantage of strategic inference too. We abstract space into automatically extracted choke points and regions of StarCraft maps from a pruned Voronoi diagram (using [71]). We then assign different scores to each of these regions and learn the influence of these scores on different attack types and locations. To do that, we set up a huge data-set of professional player's games, whose game state was extracted [29]. This work was accepted for publication at Computational Intelligence in Games (IEEE CIG) 2012 in Grenada [30] and was presented at the Computer Games Workshop of the European Conference of Artificial Intelligence (ECAI) 2012 [28].

Another focus of work this year was on army composition adaptation. RTS games unit types combinations in armies can be seen as complex (soft max) rock-paper-scissors games. Our analysis boiled to down army compositions encoded as clusters (we used a Gaussian Mixtures Model) of “classic” combinations (because of economy and technology constraints during the game). This work was published at the AI in Adversarial Real-Time Games workshop of AAAI AIIDE 2012 [29].

On top of the research/evaluation implementation, we also implemented it in our StarCraft: Broodwar’s bot implementation BroodwarBotQ. With this bot, we took part in AIIDE and CIG conferences AI tournaments placing respectively 4th (out of 10) and 6th (out of 10). Gabriel Synnaeve defended his thesis on October 24th 2012.

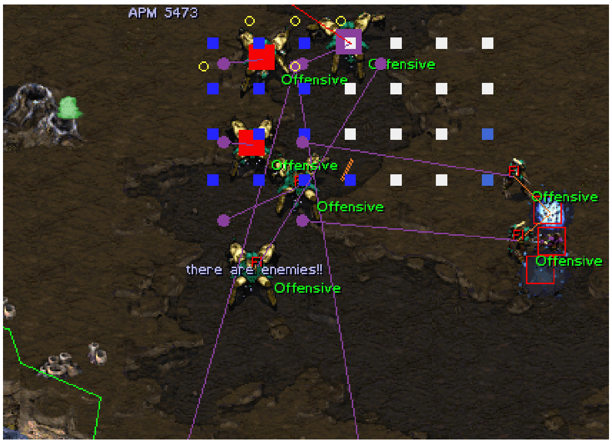


Figure 25. Units movement debugging output during a StarCraft game of the BroodwarBotQ bot. Considering the unit in the upper middle of the picture, white squares represent the highest probabilities of directions, while the darker the blue, the lower the probability to go there. The unit controller searches both to minimizes collisions and stay in range of the enemy targets (bottom right).

5.4.2. Bayesian modelling to implement and compare different theories of speech communication

Participants: Raphael Laurent, Pierre Bessière, Julien Diard, Jean-Luc Schwartz.

A central issue in speech science concerns the nature of representations and processes involved in communication. The search for phoneme or syllable specific invariants led to three major sets of approaches: motor, auditory and perceptuo-motor theories. They have been widely argued for and against, but the theoretical debate appears to be stagnating. It is our belief that computationnal models designed within a rigorous mathematical framework may allow to put forward new arguments to support either theory, and new ideas for experiments to be carried out on human subjects.

We have designed an integrative Bayesian model which allows to study auditory, motor and perceptuo-motor aspects of speech production and perception. In 2011, this model was used to work on purely theoretical simulations where we studied with diverse paradigms the decrease in the performances predicted by the different theories due to communication noise. This work led to the proof of an indistinguishability theorem : given some hypotheses on the learning process, purely motor and purely auditory models have identical answers to perception tasks. Thanks to VLAM, a vocal tract simulation tool which allows to map articulatory parameters to acoustic signals, we tested our model on vowel perception tasks. The results of both these studies are detailed in [70].

In 2012, we worked on a much more complex version of the model, which mas made able to deal with plosive syllable production and perception. A first version of this model was tested on perception tasks on evaluation corpora with more and more variability compared to the learning corpus. This showed a really high robustness of the purely motor model, which contained more information that it is the case in practise, due to unrealistic learning methods. That's why the work was then focused on more realistic learning algorithms, where speech motor gestures are unsupervisedly learned through imitation, by generating motor gestures trying to reach auditory targets, and memorising the acoustics corresponding to these motor commands.

5.4.3. Bayesian programming : book and software

Participants: Emmanuel Mazer, Pierre Bessière.

5.4.3.1. A need for a new computing paradigm

Bayesian probability theory is a mathematical alternative to logic.

However, we want working solutions to incomplete and uncertain problems. Consequently, we require an alternative computing framework based on Bayesian probabilities.

To create such a complete computing Bayesian framework, we require a new *modeling methodology* to build probabilistic models, we require new *inference algorithms* to automate probabilistic calculus, we require new *programming languages* to implement these models on computers, and finally, we will eventually require new *hardware* to run these Bayesian programs efficiently.

Our ultimate goal is a Bayesian Computer. The purpose of this book is to describe a formalism and a computer langage as first steps in this direction.

5.4.3.2. Outline of the book

Its purpose is to introduce the fundamental concepts of Bayesian Programming, to present the novelty and interest of the approach, and to initiate the reader to the Bayesian modeling. Numerous simple examples of applications are presented in different fields.

It is divided in three parts, chapters *2 Basic-Concepts* to *6: Bayesian-Program* which presents the principles of Bayesian Programming, chapters *7 : Information-Fusion* to *11 : Bayesian-Programming-Iteration* which offer a cook book for the good practice of probabilistic modeling and *12 : Bayesian Programming Formalism* to *16 Frequently Asked Question* which revisit the Bayesian inference and learning problems with the help of the presented formalism.

A fist version of the book will be send to the reviewer selected by the editor before the end of 2012

5.4.3.3. Distributed Software

One way to read this book and learn bayesian programming is to run and modify the programs given as example. A Python package "pypl" based on Probt bindings is made available with book.

The source code of the examples as well as the Python package can be downloaded free of charge.

Many examples in the book are given with parts of real corrresponding programs which could be run using the distributed package. They are given under the following format

The figure 26 has been generated using the program "chapter7/invpgm.py". The following instruction allows to get to most probable value for the heading H given the readings.

```
PH=PHkB0B1.instantiate(sensor_reading_values)
best=PH.compile().best()
```

Bayesian programs are also used to generate the illustration of the book such as this one which illustrating the navigation based on sensor fusion.

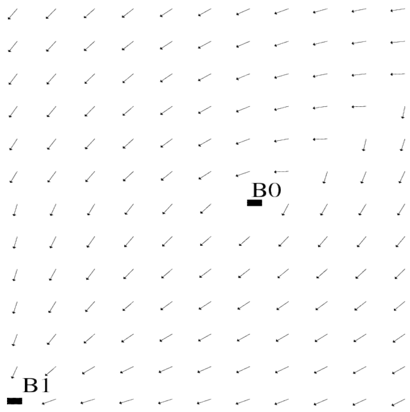


Figure 26. The vector field corresponding to $\max_h P\left(H = h | b_0 \wedge b_1 \wedge \pi\right)$

6. Bilateral Contracts and Grants with Industry

6.1. Contracts with Industry

6.1.1. Toyota Motors Europe

[Feb 2006 - Feb 2009] [Dec 2010 - Dec 2014]

The contract with Toyota Motors Europe is a joint collaboration involving Toyota Motors Europe, Inria and ProBayes. It follows a first successful short term collaboration with Toyota in 2005.

This contract aims at developing innovative technologies in the context of automotive safety. The idea is to improve road safety in driving situations by equipping vehicles with the technology to model on the fly the dynamic environment, to sense and identify potentially dangerous traffic participants or road obstacles, and to evaluate the collision risk. The sensing is performed using sensors commonly used in automotive applications such as cameras and lidar.

This collaboration has been extended for 4 years 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.

6.1.2. Renault

[Jan 2010 - Feb 2013]

This contract is linked to the PhD Thesis of Stephanie Lefèvre. The objective is to develop technologies for collaborative driving as part of a Driving Assistance Systems for improving car safety. Both vehicle perception and communications are considered in the scope of this study. An additional short-term contract (3 months) has also been signed in november 2012.

6.1.3. PROTEUS

[November 2009 - October 2013]

PROTEUS (“Robotic Platform to facilitate transfer between Industries and academics”) is an ANR project involving 6 industrial and 7 academic partners. This projects aims to develop a software platform which helps to share methods and softwares between academics and industries in the field of mobile robotics.

The project works on three main aspects :

- Specification of different scenarios and its associated formalism.
- Definition of a domain specific language (DSL) to specify and execute the given scenarios.
- Setting up 4 robotic challenges to evaluate the capacity and the usability of the platform.

The contribution of *e-Motion* to PROTEUS is first to provide its expertise on mobile robotics to develop the DSL and next to provide a simulation environment with its platform “CycabTK”.

Juan Lahera-Perez has been recruited as engineer to work on this project with Amaury Nègre.

6.1.4. Delta Drone

[9 May 2012 - 9 November 2012]

This is a collaboration between our lab and the company Delta Drone. The goal of this collaboration is the exploitation of our competences in visual inertial navigation in order to make a drone able to perform autonomous navigation in GPS denied environment. This would have a strong impact on many civilian applications (e.g., surveillance, rescue mission, building inspection, etc.) During 2012, our effort has been focused on the first important step which must be accomplished in order to perform any task: the hovering. To this regard, we introduced a new method to localize a micro aerial vehicle (MAV) in GPS denied environments and without the usage of any known pattern. This makes possible to perform hovering in an unknown and GPS denied environment. The method has successfully been implemented on the platform available in our lab. This is a *Pelican* from *Ascending Technologies* equipped with an Intel Atom processor board (*1.6 GHz, 1 GB RAM*).

6.1.5. IRT-Nano Perfect (2012-2014, and 2015-2017)

Perfect is a project supported by ANR in the scope of the IRT (Technological Research Institute) Nano-electronic driven by the CEA (Nuclear Energy Agency). The partners of the project are the CEA-LETI LIALP laboratory, ST-Microelectronics and Inria. The goal of this project is to propose integrated solutions for “Embeeded Bayesian Perception for dynamic environments” and to develop integrated open platforms. During the first phase of the project (2012-2014), the focus is on the domain of transportation (both vehicle and infrastructure); health and smart home sectors will also be considered in the second phase (2015-2017).

6.1.6. FUI Permobile (2013-2015) – submitted

Permobile is a project submitted to the 15th FUI call for project. The consortium of the project puts together research labs, large industrial partners and local small and medium companies. The objective of Permobile is to create electronic solutions (both hardware and software) for an embedded system for mobile perception in dynamic environments. This system is intended to anticipate potential collisions which may occur for the mobile platform (car, bus, aerial drone…).

The starting point is the current perception system developed in the e-Motion team for automotive applications, which is currently implemented on a standard PC (CPU+GPU) architecture. Permobile intends to improve the perception capability and to reduce the size, cost and electrical consumption of the system through the integration on the mobile technologies. A first stage consists in using current mobile technologies, while the second stage proposes to develop an innovative mobile board incorporating multiple mobile CPU/GPU processors. Demonstrators based on real mobile platforms (bus and aerial drone) will be developed to assess the realism and the efficiency of the approach developed in the project.

The partners of the project include both experts in software (Inria, Probayes), hardware (CEA LETI, Calao systems, ST-Ericsson), and final users of the technology (Delta-Drone, SEMITAG).

6.2. National Initiatives

6.2.1. Inria Large Initiative Scale PAL (Personaly Assisted Living

[Nov 2009 - Nov 2013]

The objective of this project is to create a research infrastructure that will enable experiments with technologies for improving the quality of life for persons who have suffered a loss of autonomy through age, illness or accident. In particular, the project seeks to enable development of technologies that can provide services for elderly and fragile persons, as well as their immediate family, caregivers and social groups.

The Inria Project-Teams (IPT) participating in this Large-scale initiative action Personally Assisted Living (LSIA Pal) propose to work together to develop technologies and services to improve the autonomy and quality of life for elderly and fragile persons. Most of the associated project groups already address issues related to enhancing autonomy and quality of life within their work programs. This goal of this program is to unite these groups around an experimental infrastructure, designed to enable collaborative experimentation.

Working with elderly and fragile to develop new technologies currently poses a number of difficult challenges for Inria research groups. Firstly, elderly people cannot be classified as a single homogeneous group with a single behavior. Their disabilities may be classified as not just physical or cognitive, motor or sensory, but can also be classified as either chronic or temporary. Moreover, this population is unaccustomed to new technologies, and can suffer from both cognitive and social inhibitions when confronted with new technologies. None-the-less, progress in this area has enormous potential for social and financial impact for both the beneficiaries and their immediate family circle.

The spectrum of possible actions in the field of elderly assistance is large. We propose to focus on challenges that have been determined through meetings with field experts (medical experts, public health responsible, sociologists, user associations...). We have grouped these challenges into four themes: monitoring services, mobility aids, transfer and medical rehabilitation, social interaction services. These themes correspond to the scientific projects and expectations of associated Inria projects. The safety of people, restoring their functions in daily life and promoting social cohesion are all core motivations for this initiative.

e-Motion concentrates his work on mobility aids using the wheelchair.

6.3. European Initiatives

6.3.1. Major European Organizations with which you have followed Collaborations

Department of Electrical & Computer Engineering: Univeristy of Thrace, Xanthi (GREECE)

Subject: 3D coverage based on Stochastic Optimization algorithms

BlueBotics: BlueBotics Company, Lausane (Switzerland)

Subjet: Implementation of self-calibration strategies for wheeled robots and SLAM algorithms for industrial purposes

Autonomous System laboratory: ETHZ, Zurich (Switzerland)

Subjet: Vision and IMU data Fusion for 3D navigation in GPS denied environment.

6.4. International Initiatives

6.4.1. “ict-PAMM”

[September 2011- September 2013]
ict-PAMM is an ICT-ASIA project accepted in 2011 for 2 years. It is funded by the French Ministery of Foreign Affair and Inria. This project aims at conducting common research activities in the areas of robotic mobile service and robotic assistance of human in different contexts of human life. French partners are Inria-emotion from Grenoble, Inria-IMARA from Rocquencourt and Institut Blaise Pascal from Clermont-Ferrand. Asian Partners are IRA-Lab from Taiwan, ISRC-SKKU from Suwon in Korea, ITS-Lab from Kumamoto in Japan and Mica Institute from Hanoi in Vietnam.

6.4.2. “Predimap”

[September 2011- September 2013]

Predimap is an ICT-ASIA project accepted in 2011 for 2 years. It is funded by the French Ministery of Foreign Affair and Inria. This project aims at conducting common research activities in the area of perception in road environment. The main objective is the simultaneous use of local perception and Geograpical Information Systems (GIS) in order to reach a global improvement in understanding road environment. Thus the research topics included in the project are: local perception, precise localization, map-matching and understanding of the traffic scenes. French partners are Inria-emotion from Grenoble, Heudiasyc team from CNRS/UTC, and Matis team from IGN. Foreign partners are Peking University and Shanghai Jiao Tong University in China, CSIS lab from Tokyo University in Japan and AIT Geoinformatics Center in Thailand.

6.4.3. *“PRETIV”*

[November 2011- October 2014]
Multimodal Perception and REasoning for Transnational Intelligent Vehicles" (PRETIV) is a three-year ANR project accepted in the framework of the Blanc International II Programme with participants from France (e-Motion of Inria, Heudiasyc of CNRS, PSA Peugeot Citroen DRIA in Velizy) and China (Peking University, PSA Peugeot Citroen Technical Center in Shanghai). The project aims at developing of an online multimodal perception system for a vehicle and offline reasoning methods, dealing with incompleteness and uncertainties in the models and sensor data, as well as at conducting experiments in typical traffic scenarios in France and China to create an open comparative dataset for traffic scene understanding. The perception system will incorporate vehicle localization, mapping of static environmental objects, detecting and tracking of dynamic objects in probabilistic frameworks through multimodal sensing data and knowledge fusion. The reasoning methods are based on sensor data to learn semantics, activity and interaction patterns (vehicle - other objects, vehicle - infrastructure) to be used as a priori information to devise effective online perception algorithms toward situation awareness. The comparative dataset will contain experimental data of typical traffic scenarios with ground-truth, which will be used to learn country-specific traffic semantics and it will be open to the public.

6.4.4. *Visits of International Scientists*

In 2011, M. Perrollaz went to Ohio Northern University for a short term research contract. From this collaboration, two papers were published in 2012: [24] and [33].

In 2012, Dimitrios Kanoulas, PhD Student at Northeastern University (Boston, USA) came at Inria for 4 months, within the framework of the REUSSI program.

6.4.4.1. Internship

Procopio Silveira-Stein, phD at LAR (Laboratório de Automação e Robótica) at UA (Universidade de Aveiro) is in our team for november 2011 to july 2012.

6.4.5. *Participation In International Programs*

Submission of a international program with Taiwan called I-Rice. Partners for this proposition of an international center are IRA-lab (Taiwan university), LAAS, Inria and UPMC. Topics are related to Cognitive Systems and Robotics. Project under evaluation (hearing step).

Submission of an ANR Blanc GeoProb in collaboration with the spinoff Probayes (Mexico). Project on complementary list.

7. Dissemination

7.1. Animation of the scientific community

7.1.1. *conferences and workshops*

- C. Laugier organised a workshop on intelligent vehicles during IROS’12.
- C. Laugier was program chair of IEEE/RSJ IROS 2012 conference in Vilamoura (Portugal, oct. 2012).

- C. Laugier co-organised workshop at the IEEE/RSJ IROS 2012 conference in Vilamoura (Portugal, oct. 2012).
- A. Spalanzani organised a workshop on Assistance and Service robotics in a human environment during IROS'12.
- C. Laugier was member of the conference editorial Board and member of the Program Committee of the IEEE ICRA 2012 conference (Mineapolis, may 2012).
- A. Spalanzani was associate editor of the Ro-Man 2012 conference.
- A. Martinelli was Associate Editor at ICRA 2012.
- C. Laugier co-organized with Philippe Martinet a workshop on intelligent vehicles during IEEE/RSJ IROS'12 in Algarve (Portugal).
- A. Spalanzani co-organized with D. Daney, JP Merlet and O. Simonin a workshop on Assistance and Service robotics in a human environment during IEEE/RSJ IROS'12 in Algarve (Portugal).
- C. Laugier has been appointed as program co-chair at the IEEE/RSJ IROS 2012 conference(Algarve, Portugal).
- C. Laugier is co-chair of the IEEE RAS Technical Committee on "Autonomous Ground Vehicles and Intelligent Transportation Systems". He co-organized in this scope several scientific events in 2012 (workshops, special sessions of International conferences, a journal special issue in "Robotics and Automation Magazine" to be published in 2013). - C. laugier was Associate Editor for the part "Fully Autonomous Driving" of the Springer "Handbook on Intelligent Vehicles" published in March 2012.
- C. Laugier has been invited as an Associated Editor (with A. Zelinsky, A. Broggi and U. Ozgüner) for chapter "Intelligent Vehicles" of the 2nd edition of the Springer "Handbook of Robotics" to be published in 2013-14.
- A. Spalanzani co-organised a workshop at the IEEE/RSJ IROS 2012 conference in Vilamoura (Portugal, oct. 2012).
- C. Laugier was member of the conference editorial Board and member of the Program Committee of the IEEE ICRA 2012 conference (Mineapolis, may 2012)
- C. Laugier was program chair of IEEE/RSJ IROS 2012 conference in Vilamoura (Portugal, oct. 2012)
- C. Laugier co-organised workshop at the IEEE/RSJ IROS 2012 conference in Vilamoura (Portugal, oct. 2012).
- C. Laugier was a member of the program committee of the FSR 2012 conference (Japan, march 2012)

7.1.2. invited talks

- C. Laugier has given a seminar entitled "Autonomous Mobility in Human Environments" at the University of Tokyo on March 2012.
- C. Laugier has given an invited talk entitled "Situation Awareness and Collision Risk Assessment: Application to Autonomous Vehicles in Open Dynamic Environments" at the Workshop on Field and Service Robotics in Sendai on March 2012.
- C. Laugier and S. Lefevre have given an invited talk entitled "Embedded Perception and Situation Awareness for improving Driving Safety" at the 2nd Workshop Berkeley-Inria-Stanford in Paris on May 2012.
- C. Laugier has given an invited talk entitled "Human Centered Robotics and Mobility" at the NTU-IRiCE Workshop on Robotics and Automation in Taipei on May 2012.

7.1.3. others

- A. Spalanzani, M. Perrollaz, P Stein, A. Escobedo, J. Rios and C. Laugier have presented the robotic wheelchair at the innorobo 2012 fair, march 2012.
- C. laugier participated as panelist expert to the large public event "Talents de Rhône-Alpes: Homme/Robot qui aura la main?" in Lyon on December 18th 2012.
- F. Breton and C. laugier have published a vulgarization article entitled "Les robots apparaissent dans l'espace de vie des humains", October 2012.
- A. Martinelli was reviewer of the PhD thesis of Stephan Weiss at ETHZ in March 2012.
- A. Spalanzani and C. Laugier participated to the organization of the French-Mexican summer school on robotics and vision (SSIR'12) in Ensenada (Mexico).
- M. Perrollaz made a talk at the "Fête de la science", oct 2012.

7.2. Teaching

- Master MOSIG: “autonomous Robotics”, C. Laugier (responsible), A. Martinelli, M. Perrollaz, A. Nègre, 24h, M2, MOSIG-INP, France.
- Master CNAM: “Basic technologies for autonomous Robotics”, C. Laugier, CNAM, France.
- Doctorat (école d’été): “autonomous Robotics”, C. Laugier, 6h, SSIR’12, Ensenada, June 2012, Mexico.
- Ecole d’Ingénieur : “Programmation structurée en C”, M. Perrollaz, 36h, L3, Phelma, Grenoble-INP, France.

PhD & HdR :

- PhD in progress: Chiara Troiani, vision and inertial sensor fusion for 3D navigation, 2011, A. Martinelli.
- PhD in progress: Jorge Rios-Martinez, Comfortable navigation using social conventions, 2009, A. Spalanzani.
- PhD in progress: Arturo Escobedo, Shared Control navigation, 2011, A. Spalanzani.
- PhD in progress: Raphael Laurent, Bayesian modelling to implement and compare different theories of speech communication, 2011, P. Bessière.
- PhD in progress: Stéphanie Lefèvre, context-aware bayesian filtering for collision prediction at roads intersections, defended in 2012, C. Laugier
- PhD in progress: Gabriel Synnaeve, Bayesian programming applied to a multi-player video games, defended in 2012, P. Bessière.
- PhD in progress: Alessandro Renzaglia, 3D coverage by using stochastic approach, defended in 2012, A. Martinelli.

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Publications of the year

Doctoral Dissertations and Habilitation Theses

[9] S. LEFÈVRE. *Risk Estimation at Road Intersections for Connected Vehicle Safety Applications*, Université de Grenoble, October 2012.

[10] A. RENZAGLIA. *Optimisation stochastique et adaptative pour surveillance coopérative par une équipe de micro-véhicules aériens*, Université de Grenoble, April 2012, http://hal.inria.fr/tel-00721748.

[11] G. SYNNAEVE. *Programmation bayésienne et apprentissage pour les jeux vidéo multi-joueurs : une application à l'IA de jeux de stratégie en temps réel*, Université de Grenoble, October 2012.

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[12] L. DOITSIDIS, S. WEISS, A. RENZAGLIA, M. ACHTELIK, E. KOSMATOPOULOS, R. SIEGWART, D. SCARAMUZZA. *Optimal surveillance coverage for teams of micro aerial vehicles in GPS-denied environments using onboard vision*, in "Autonomous Robots", 2012, http://hal.inria.fr/hal-00692534.

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