INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team e-Motion

Geometry and Probability for Motion and Action

Rhône-Alpes

THEME NUM

Activity Report

2004

Table of contents

1. Team

Head of Project-Team
Christian Laugier [Inria DR]

Administrative Assistant
Anne Pasteur [Inria]

Inria Staff
Thierry Fraichard [CR]
Sepanta Sekhavat [CR in Iran for 2 years]

CNRS Staff
Emmanuel Mazer [DR currently at Probayes]
Pierre Bessière [CR]

Faculty Member
Olivier Aycard [UJF[1] Associate Professor]
Anne Spalanzani [UPMF[2] Associate Professor]

Project Technical Staff
Juan-Manuel Ahuactzin Larios [2001-2004]
Olivier Malrait [2002-2004]
Kamel Mekhnacha [2002-2004]
Fernando De la Rosa [2004-2005]
Christophe Coué [2004]

Research Scientist (Partner)
Julien Diard [LPPA, Collège de France]

Post-doctoral fellow
Jorge Hermosillo Valadez [2004]
Kenneth Sundaraj [up to april 2004]

Ph.D. Students
Miriam Amavicza [Mexican CONACYT/SFERE fellowship]
Francis Colas [Inria fellowship]
Pierre Dangauthier [MENESR fellowship]
Alejandro Dizan Vasquez Govea [Mexican CONACYT/SFERE fellowship]
Carla Koike [Brazilian CAPES fellowship]
Ronan Le Hy [MENESR fellowship]
Cédric Pradalier [MENESR fellowship]
Manuel Yguel [CIFRE fellowship]

Co-directed Ph.D.students
Mikail Kais [INRIA fellowship, co-directed with I. Masaki, MIT]
Stéphane Petti [industrial fellowship,AW Europe]
Brice Rebsamen [NUS fellowship France-Singapore co-directed with E. Burdet, NUS]

Student Intern
Christophe Braillon [DEA IVR]
Julien Burlet [DEA III]
Ruth Lezama-Morales [DEA IVR]
Eva Simonin [DEA III]
Chritopher Tay [DEA IVR]

---

[1]Université Joseph Fourier, Grenoble.
[2]Université Pierre Mendès France, Grenoble.

Visiting Scientist
Jose Luis Gordillo [ITESM Monterrey - July 2004]

2. Overall Objectives

2.1. Overall Objectives

2.1.1. Keywords

Computational geometry, Bayesian programming, Automatic learning, Automatized motions and actions, Space-time reasoning, Biologic inspiration, Robotics

2.1.2. Project-team presentation overview

Challenge: The project-team *e-Motion* aims at developing models and algorithms allowing us to build *"artificial systems"* including advanced sensori-motors loops, and exhibiting sufficiently efficient and robust behaviors for beeing able to operate in *open and dynamic environments* (i.e. in partially known environments, where time and dynamics play a major role), and leading to *varied interactions with humans*. Recent technological progresses on embedded computational power, on sensor technologies, and on miniaturised mechatronic systems, make the required technological breakthroughs potentially possible (including from the scalability point of view).

Approach and research themes: In order to try to reach this objective, we propose to combine the respective advantages of the *computational geometry* and of the *theory of probabilities*, while working in cooperation with neurophysiologists for trying to apply and experiment some *biological models*. This approach leads us to study, under these different points of view, three strongly correlated fundamental research themes:

- *Multimodal and incremental modelling of space and motion*. The basic idea consists in continuously building (using preliminary knowledge and current perceptive data) several types of models having complementary functional specialisations (as suggested by neurophysiologists). This leads us to address the following questions : how to model the various aspects of the real world ? how to consistently combine a priori knowledge and flows of perceptive data ? how to predict the motions and behaviors of the sensed object ?
- *Motion planning for the physical world*. The main problem is to simultaneously take into account various constraints of the physical world such as non-collision, environment dynamicity, or reaction time, while mastering the related algorithmic complexity. Our approach for solving this problem consists in addressing two main questions : how to construct incrementally efficient space-time representations ? how to define an iterative motion planning paradigm taking into account kinematics, dynamics, and time constraints ?
- *Probabilistic inference for decision*. The problem to solve is to be able to correctly reason about both the current knowledge of the system and the associated uncertainties. Our approach for addressing this problem is to make use of the bayesian programming paradigm, by developping the related models and computational tools.

Application domains: The main applications of this research are those aiming at introducing advanced and secured robotized systems into the human "living space". In this context, we are focussing onto applications such as future cars and transportation systems, or service and intervention robotics (e.g. domestic tasks, civilian or military safety, entertainment). In cooperation with our spin-off company *Probayes*, we are also exploiting some spin-offs of our bayesian programming technique in application domains such as the diagnosis for the preventive maintenance of complex industrial plants, or the assistance to some financial decisions.

3. Scientific Foundations

3.1. Background

In spite of the significant technological advances made during the last decade, Robotics is still blocked by the problems of *scalability* and of the *real integration of robotised systems in our everyday life*. The reason for this stems primarily from the fact that models and technologies developed in the past (e.g. approaches based on logics, geometrical based methods, randomized search techniques, reactive architectures ...) have mainly reached their limits, and cannot be directly used for crossing the complexity gap introduced by the physical environments in which we are living. Indeed, such environments include complex multimodal data, are continuously changing and partially unpredictable, and generate complex interactions with humans. This means that *appropriate decision-making processes* taking into account these characteristics have to be designed, implemented and experimented in real situations. Such processes have to be efficient and robust enough for making it possible to meet the required reactivity characteristics, while beeing able to make appropriate decisions from complex and incomplete data and knowledges, i.e. by reasoning about a combination of partial a priori knowledges, of some incremental experimental data (including sensory data), and of some hidden variables. This means that new models and algorithms have to be designed for beeing able to formalise the intrinsic *"incompleteness"* of the problem, and to better model the intricate *"complexity"* of the real world.

3.2. Problems Addressed

The objective of the *e-Motion* project-team is to find formal and practical solutions to the previous unsolved problems, still very little addressed by our scientific community. Our bet is that our new approach based on both geometry and bayesian programming, will allow us to achieve the following technological breakthroughs:

- *Motion autonomy in a dynamic complex world.* We are especially interested in the problems arising from the richness of the environments considered (i.e. how to model them efficiently), from their dynamicity (i.e. taking explicitly into account the "space-time" dimension), and from the large variety of possible interactions (e.g. estimation and prediction of the behaviors of the potential obstacles).
- *Increased robustness of the automatic navigation processes.* We put the emphasis on the problems of *incompleteness* (factors not taken into account or hidden variables) inherent to the representation of any physical phenomenon. This dimension of the problem is generally empirically and approximatively taken into account in traditional approaches, leading the related systems to be poorly reliable. Our approach for dealing with this problem is to convert the "incompleteness" into numerically quantifiable data, coded in terms of probability distributions and referred to as *"uncertainties"*. Then, such random variables can be combined, evaluated, and used in various decision-making processes.
- *Intuitive programming of artificial systems and of their associated reactive processes.* Our approach consists in using as far as possible *learning* processes (supervised or not), in order to be able to combine the a priori knowledge (called "preliminary data") and the past experience of the system (called "experimental data"); this approach should permit us to gradually obtain systems more robust and better adapted to the problems at hand. We will use and generalize our new concept of *Bayesian Programming* for developing the required processes.

4. Application Domains

4.1. Application Domains

As previously mentionned, the main applications of our research are those aiming at introducing advanced and secured robotized systems into the human "living space". In this context, we are focussing onto the following application domains :

- *Future cars and transportation systems.* This application domain should quickly change under the effects of both new technologies and current economical and security requirements of our modern society. Various technologies are currently studied and developed by research laboratories and industry. Among these technologies, we are interested in *ADAS*[3] systems aimed at improving comfort and safety of the cars users (e.g. ACC, emergency braking, danger warnings ...), and in *Automatic Driving* functions allowing fully automatic displacements of private or public vehicles in particular driving situations and/or in some equipped areas (e.g. automated car parks or captive fleets in downtown centres).
- *Service and intervention robotics.* This application domain should really explode as soon as robust industrial products, easily usable by non-specialists, and of a reasonable cost will appear on the market. One can quote in this field of application, home robots (such as for example current vacuum cleaning robots which are both too expensive and poorly efficient), active surveillance systems (e.g. surveillance mobile robots, civilian or military safety, etc.), entertainment robots (such as for example the Sony robots *Aibo* or *Qrio*), or robotised systems for assisting elderly and/or to disabled people. The technologies we are developing should obviously be of a major interest for such types of applications.
- *Potential spin-offs in some other application domains.* The software technologies we are developing (for bayesian programming) should also have a potential impact on a large spectrum of application domains, covering fields as varied as the interaction with autonomous agents in a virtual world (e.g. in the video games), the modelling of some biological sensory-motor systems for helping neurophysiologists to understand living systems, or applications in economic sectors far away from robotics like those of finance or plant maintenance (applications currently covered by our start-up *Probayes* commercializing products based on Bayesian programming).

5. Software

5.1. Advanced Software

- *ColDetect. People involved : Christian Laugier, Kenneth Sundaraj*. This library has been implemented for providing robust and efficient *collision detection, exact distance computation, and contact localisation of three-dimensional polygonal objects*. These objects can be concave or convex, rigid or deformable. The library is numerically robust, i.e. the algorithm is not subject to conditioning problems and requires no special handling of nongeneric cases. ColDetect has been implemented in standard C++ and relies heavily on STL in order to be as fast and memory efficient. Currently it compiles under GNU g++ version 2.95 and 3.2. *ColDetect* is patented under the french APP patent #IDDN.FR.001.280011.000.S.P.2004.000.10000.

[3] Advanced Driver Assistance Systems

- *ProBT. People involved : Juan-Manuel Ahuactzin, Kamel Mekhnacha, Pierre Bessière, Emmanuel Mazer, Manuel Yguel, Olivier Aycard.* 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 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.
- *Cycab Simulator. People involved : Cédric Pradalier.* In order to perform pre-test and to provide help for Cycab developers, a Cycab simulator has been developed. This simulator is intended to simulate hardware and low-level drivers, in order to produce a temporal behaviour (refresh frequency, scheduling...) similar to what can be found on the Cycab. Furthermore, a hierarchy of C++ classes has been developed in order to keep a consistent interface between the simulated CyCab and the real one. Applications written and tested on the simulated robot can then be settled to the real one with only minor modifications (instantiating one class or the other). Sensors and environment are also simulated, so that complete applications can be developed on this test bed. Finally, we also provide developer with an TCP/IP controllable Cycab, consistent with simulated and real Cycab in term of C++ interface. The Cycab Simulator is currently widely used by the researchers of the *e-Motion* project-team; it has also been used in a collaboration with the RIA team (LAAS, Toulouse), and with the LAG laboratory (IMAG, Grenoble). A recent extension of the system is also used for student home-work in the scope of robotics courses (Summer school on image & robotics 2004, and Master IVR at ENSIMAG Grenoble 2004-05).
- *VisteoPhysic. People involved : Cesar Mendoza, Kenneth Sundaraj, Christian Laugier.* This library provides efficient tools for deformable object simulation. It includes the Finite Element Method (FEM) and the Long Element Method (LEM) deformable models for physical simulation. It also has interactions models for collision detection, exact distance computation, and contact localization of three-dimensional polygonal objects. These objects can be concave or convex, rigid or deformable. This library is numerically robust - the algorithms are not subject to conditioning problems, and requires no special handling of nongeneric cases. *VisteoPhysic* has been implemented in standard C++ and relies heavily on STL in order to be as fast and memory efficient. The library was developed in collaboration with XL-Studio and is patented under the french APP patent #IDDN.FR.001.210025.000.S.P.2004.000.10000

5.2. Prototype Software

- *VDM. People involved : Kenneth Sundaraj, Christian Laugier*. This library provides efficient tools for real-time simulation of biological tissue. It is based on a new physical model called the Volume Distribution Method (VDM). This physical model is based on Pascal's principle and uses volume conservation as boundary conditions. This software is distributed freely on the internet under a GPL license. Currently, this software has been used in a prototype system of an echographic thigh exam simulator and an arthroscopy knee reconstruction simulator for the ACL ligament. This work was within the framework of a collaboration with Aesculap-Bbraun (Navigation systems for surgery). VDM version 1.0 has a french APP patent #IDDN.FR.001.280012.000.S.P.2004.000.10000

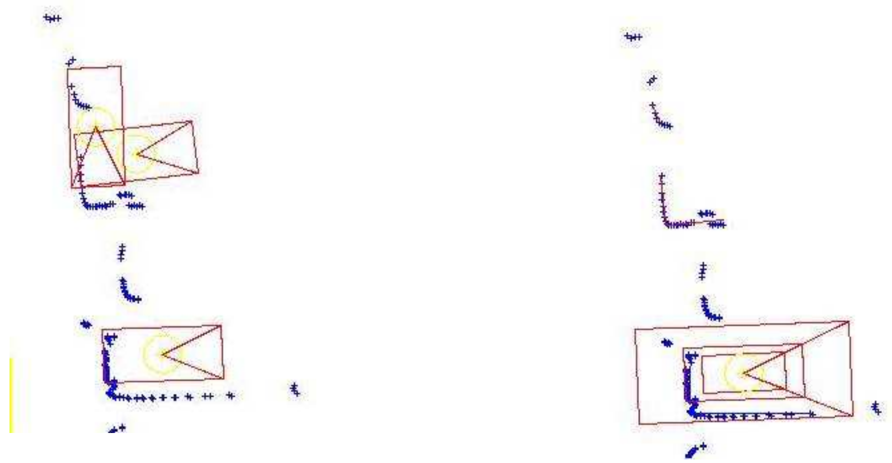


Figure 1. (left) Detected vehicles after first stage filtering. (right) Detected vehicles after second stage filtering

6. New Results

6.1. Multimodal and Incremental Modelling of Space and Motion

6.1.1. Simultaneous Localization and Mapping in Changing Environments

Participants: Cédric Pradalier, Christophe Braillon, Christopher Tay Meng Keat, Christian Laugier.

Simultaneous Localization And Mapping (SLAM) is a well known problem in the robotic community as long as static environments are concerned. The problem of SLAM involves incrementally building a map of its environment as an autonomous robot localizes itself with respect to the map it had built. Since 2002, we have demonstrated our ability to perform localization and mapping in such an environment[18][14].

To extend our knowledge on this field, we initiated this year a research thread on localization and mapping in a changing environment. We consider the case of a CyCab robot equipped with a Sick laser range finder evolving on a car park with occupied and free parking lots. With this sensor in such an environment, the robot can only sense cars, either parked or moving. We have a three step objective: firstly to extract hypothesized cars from sensor output; secondly, to use these hypothesized cars to build a car map of the parking area, i.e. to build a map of parked car, being able to detect when a new car is parked or when a parked car left; thirdly, using static cars as landmarks, we can refine our position estimation in the car park and estimate other cars' movement.

The first part of this work was conducted last year by a master student (J. Lorieux, [69]). What was obtained was the static extraction of vehicle hypothesis from laser range data which constitutes the first stage of the vehicle hypothesis filtering process.

This year, the second objective was achieved by a second master student (C. Tay Meng Keat, [43]). We managed to improve the robustness of the vehicle extraction by performing strict double checking during the second stage of vehicle hypothesis filtering.

Figure 1 (left) shows hypothesized cars (rectangles) extracted from a laser scan, whereas Figure 1 (right) shows remaining hypotheses after our improved filtering method.

In order to build a map of the car park, we wanted to implement SLAM techniques, using the extracted hypothesised vehicle as landmarks. Amongst existing SLAM techniques, we chose to use the method FastSLAM [73]. The idea behind this method is that knowing the full trajectory of the robot, the state of the landmarks are conditionnally independant. This leads to computational simplication and consequently a fast and efficient algorithm, for which it is particularly suitable for realtime applications.

In FastSLAM implementations, the probability distribution on the robot state is represented by a cloud of particles (as in particle filters [47]). The specific characteristic of FastSLAM is that each particle contains its own estimation of the map, i.e. the estimation of the map knowing the full trajectory since the start. Consequently, when we need a usable representation of the map (for path planning for instance), we have to fuse all the map hypotheses contained in all the particles. This year, we have proposed an algorithm to implement, in a quite robust way, this fusion process allowing the construction of the final map [43].

These results have been submitted to the ICRA'05 conference. Furthermore, C. Tay Meng Keat is beginning a PhD thesis centered on the simultaneous localization and mapping of a dynamic environment, which corresponds to the third objective.

6.1.2. Bayesian Maps

Participants: Julien Diard, Pierre Bessière, Eva Simonin.

This work concerns the hierarchical and bio-inspired modeling of navigation capacities, using the Bayesian formalism. Our main previous contribution in this domain is a framework developped during Julien Diard's PhD, called the Bayesian Map formalism [58].

In 2004, we have been interested in two domains of application of this model:

- *Robotics*. We have first argued [22] that the Bayesian Map formalism is a possible mariage between, on the one hand, "bio-inspired models" (which are a promising tool for developping flexible navigation skills in mobile robots) and, on the other hand, "hierarchical solutions", which are needed to model larger environments than what is possible in state-of-the-art control architectures. The Bayesian Map formalism we have developped has been also successfully applied on a Koala robot during proof-of-concept experiments. For instance, we have demonstrated that it was possible to use Bayesian inference as a way to model high-level localization as a "recognition" of lower-level sensory-motor models [23]. We are also currently developping a full-scale control architecture using the Bayesian Map formalism, including the learning of the sub-models as well as of the way sub-models are articulated [46] [77]. We also aim at integrating the notion of hierarchical and bio-inspired models of navigation in the context of probabilistic path planning [76].
- *Cognitive modeling*. Part of this research track has been done in collaboration with the Laboratory of Physiology of Perception and Action, Collège de France, Paris, during Julien Diard's post-doctoral visit there. In this domain, we are arguing that the Bayesian Map framework is a promising tool for modeling human navigation skills [42]. Indeed, on the one hand, it is based on the probability calculus which helps treat uncertainties and decision making in a mathematically sound manner. On the other hand, it offers modeling tools for modular and hierarchical systems, which probably are the best tools for understanding human navigation as a sum of sub-systems (for instance, sub-systems that deal with parts of the environment, part of the sensory input, part of the navigation task to solve, etc). The Bayesian Map formalism proposes mathematical operators for modeling the way such sub-systems can be articulated. For instance, we have developped a Bayesian model of the coordination between two cognitive strategies (landmark-based navigation and path integration) in humans involved in a navigation task in a virtual environment [24][30]. This model qualitatively describes errors made by human participants when cues used for memorising paths are removed and missing for the reproduction of the path. Current research is aimed at precising the model, in particular at modeling the influence of geometrical and visual landmarks in path memorisation.

6.1.3. Moving Objects' Future Motion Prediction

Participants: Thierry Fraichard, Alejandro Dizan Vasquez Govea, Christian Laugier.

To navigate or plan motions for a robotic system placed in an environment with moving objects, reasoning about the future behaviour of the moving objects is required. In most cases, this future behaviour is unknown and one has to resort to predictions. Most prediction techniques found in the literature are limited to short-term prediction only (a few seconds at best) which is not satisfactory especially from a motion planning point of view.

In 2003, we have started to explore the problem of medium-term motion prediction for moving objects. As a result, we have proposed a novel cluster-based technique that learns typical motion patterns using pairwise clustering and use those patterns to predict future motion [35].

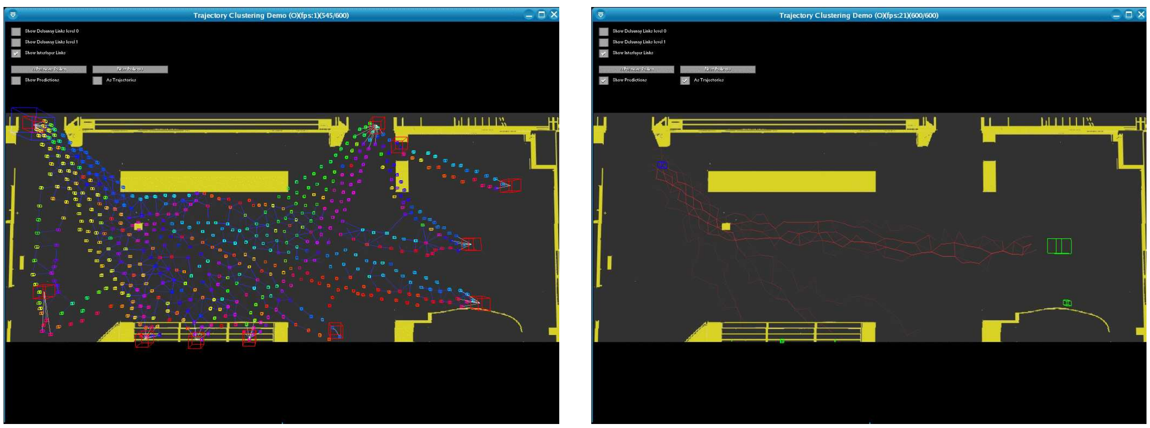


Figure 2. Learning (left): small boxes correspond to the states found by the SOM. Red boxes are high-level goals or policies. Links indicate transitions (bluer is more probable). Prediction (right): the blue box corresponds to the actual object position, green boxes represent the belief about the high level goal (bigger is more probable). Red lines correspond to the predicted trajectories (redder is more probable

During 2004, we have developed a number of libraries and utilities (environment modelling, sensor modelling, camera calibration, communications) that will be used for further experiments. On the theoretical side, we have started to work on a new technique whose purpose is to address a number of issues that were not solved by our first approach:

- *Prediction of unobserved patterns:* our first approach was not able to address a situation where a moving object would "change its mind" and switch from one typical motion pattern to another one. The new approach which relies upon the notion of goals rather than typical motion patterns will be able to address this kind of problem.
- *On-line/adaptive learning:* the clustering technique used in our first approach is an off-line process taking as input a data set of observed trajectories. The new learning technique will be able to learn on-line, *ie* to take into account newly observed trajectories while carrying out the prediction.

The approach we are developing operates at two levels:

- *State Representation:* space sampling should be dense in interesting areas and coarse in areas where nothing happens. For this, we are working on discretisation using a self-organised map (SOM) known as the Growing Neural Gas [63]. One of the main advantages of this approach is that it is adaptive and works on-line (Fig. 2).

- *Object Motion Modelling:* motion is modelled as being dependent on a plan, the plan itself is hierarchically decomposed into subgoals which, at the lowest level, correspond to probabilities of transition between states. The specific model we are focusing on is the Abstract Hidden Markov Model [51]. Thanks to the chosen state representation, it is possible to learn transition probabilities at the same time that we are constructing the state representation (Fig. 2).

6.1.4. Dynamic Scenes Interpretation by Bayesian Data Fusion

Participants: Pierre Bessière, Christophe Coué, Thierry Fraichard, Manuel Yguel, Olivier Aycard, Christian Laugier.

Unlike regular cruise control systems, Adaptive Cruise Control (ACC) systems use a range sensor to regulate the speed of the car while ensuring collision avoidance with the vehicle in front. ACC systems were introduced on the automotive market in 1999. Since then, surveys and experimental assessments have demonstrated the interest for this kind of systems. They are the first step towards the design of future Advanced Driver Assistance Systems (ADAS) that should help the driver in increasingly complex driving tasks. The use of today's commercially available ACC systems is pretty much limited to motorways or urban expressways without crossings. The traffic situations encountered are rather simple and attention can be focused on a few, well defined detected objects (cars and trucks). A wider use of such systems requires to extend their range of operation to more complex situations in dense traffic environments, around or inside urban areas. In such areas, traffic is characterized by lower speeds, tight curves, traffic signs, crossings and "fragile" traffic participants such as motorbikes, bicycles or pedestrians. A prerequisite to a reliable ADAS in such complex traffic situations is an estimation of the dynamic characteristics of the traffic participants, such as position and velocity. This problem can be seen as a *Multi-Target Tracking* problem. Classical approaches of Multi-Target Tracking are designed for military applications [48] and therefore do not answer urban driving specificities. Numerous methods (JPDA, PMHT, etc.) consider known and constant number of targets. Other methods (MHT) allow the creation of new tracks, but they are intractable in situations involving numerous appearances, disappearances and occlusions of a large number of rapidly manoeuvering targets.We have chosen to express the problem of environment representation in a different way. We prefer to estimate the occupied and free space of the environment of our vehicle in a 4 dimensions grid, including 2D-positions and 2D-velocities. We called the corresponding model the *Bayesian Occupancy Filter (BOF)* [53]. This model is inspired by *occupancy grids* which have been extensively used for mapping and localisation in static environments.

In 2003, to demonstrate the tractability and the relevance of the BOF, a collision avoidance behavior in a dynamic environment has been implemented on the Cycab robot [54].

These experimentations have shown that the main problem of mapping through *bayesian occupancy filter (BOF)* is the amount of data structure it needs. In fact this approach deals with dense information in 4 dimension. So all algorithms using this kind of data representation have to work on small areas. To avoid this restriction we work on a new representation of this data using multiscaled time-space representations like wavelets (Fig. 3). We assume that urban area are localy very regular at men scale. By example, walls surround buildings which have often regular shapes and zero velocity, and roads separate them. So, we represent them with patches of free space for roads and occupied space with zero velocity for buildings. In this terms we can filter 4D map data to resume occupancy space with 4D standard patches at different scales. We only work with a list of patches instead of raw cells from discretized high dimensionnal space. This technique is under test in real urban environments with the puvame project. The Cycab robot is used to simulate bus motion in crossroads with pedestrian displacements and parked vehicles which could hide each other.

6.1.5. Perception of Shapes From Motion

Participants: Francis Colas, Pierre Bessière.

One issue in the modelling of space is the perception of its structure. *Structure from Motion* (SfM) is a way to extract some geometrical information from the optic flow generated by the movement either of an object or the observer ([64]). Sfm is a common field of interest to both computer vision and experimental physiology.

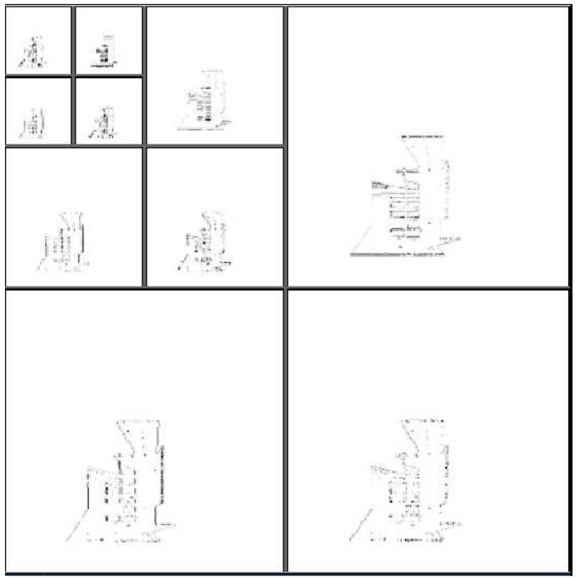


Figure 3. Wavelet decomposition of INRIA Rhône-Alpes parking map. The map was constructed with SLAM algorithm by Cycab sensors and the decomposition using LastWave program[4]

Within the framework of the BIBA project, we have investigated this year the psychophysical findings on human perception of shapes from motion. We were particularly interested in the optic flow of a plane that presents several amiguities. Recovering geometry from optic flow is then an inverse and ill-posed problem. We proposed in [41] a bayesian program to take into account different results integrate them into a single model. So far we were able to reproduce the results of five psychophysical experiment such as the difference between active and passive performance or the shear or (winding angle) effect described in [78]. Thus bayesian modelling has been an adequate framework to deal with this inverse and ill-posed problem

6.2. Interactive Simulation

Participants: Kenneth Sundaraj, Miriam Amavizca, Ruth Lezama-Morales, Juan Manuel Ahuactzin.

This year, in this research topic related to the previous Sharp project, we have contributed in the following:

- Soft Tissue Simulation
- Bayesian Collision Detection
- Computer Aided Surgery

6.2.1. Soft Tissue Simulation

We have completed the development of our new physical model for soft tissue simulation. This model, called the Volume Distribution Method (VDM), has been implemented and packaged into a freeware library under an APP patent. The VDM model is derived from bulk variables like pressure and volume. In terms of complexity, this new model is one order of magnitude lower than classical volumic models like the Finite Element Method (FEM) [52]. Pascal's principle and volume conservation are used as boundary conditions. Since volume conservation is observed in soft tissue, the VDM model is a suitable choice. Furthermore, its lower complexity makes it an interesting alternative for interactive-time applications.

6.2.2. Bayesian Collision Detection

On the past, the collision detection problem has been tackled from the exact point of view. That is, given the configurations of two geometric entities, the response of a collision detection algorithm is: “in collision” or “not in collision”. In the *e-Motion* team, we are exploring the collision detection problem from the probabilistic point of view. In this case, the response of the collision detection algorithm is: “the probabillity of collision is q” where q belongs to the interval $[0,1]$. The main advantage of this approach is speediness. In effect computing q only requires of a few of multiplications.

Numerous Virtual Reality or Robotics applications do not require of an exact collision detection. We believe that this schema can be used for developing applications where (i) the collision detection does not have to be exact (such as 3D video games) and (ii) the fast yes/not collision detection answer is required (e.g. in dynamic situations).

In order to compute the “probability of collision” between two entities, we are using a sensor fusion scheme. The fusion of n sensor distributions computes the probability of the collision variable. The sensor distributions are computed in a off-line learning phase, and stored in the mesh data base. When an application loads a set of meshes, the sensor distributions are also loaded. The Bayesian detection algorithm uses this data to compute the probability of collision for a given set of pairs.

Our preliminary experimental results shows that this approachs is promising. Here we depict one of our experiments inspired from motion planning. It consists in simulating the fall of the stick on a torus. At the beginning the stick is placed at the center top position of the bounding sphere of the torus. At each time iteration the position on z is decremented of Δz while x and y remains constant. The orientation is chosen (with our algorithm) so that the probability of collision is minimized. These minimization is executed in a vicinity of the configuration at time $(t-1)$. The result is shown on Figure 4. As it can be seen, the stick is oriented so that it avoids the collision while crossing the center of the torus.

Our preliminary results are very encouraging. In effect, if we consider that two configurations are in collision if $p \geq p_0$ then the obtained presicion is p_0. The running time of the Bayesian program is the time required to realizing a few multiplication, as much as the double of the number of virtual sensors.

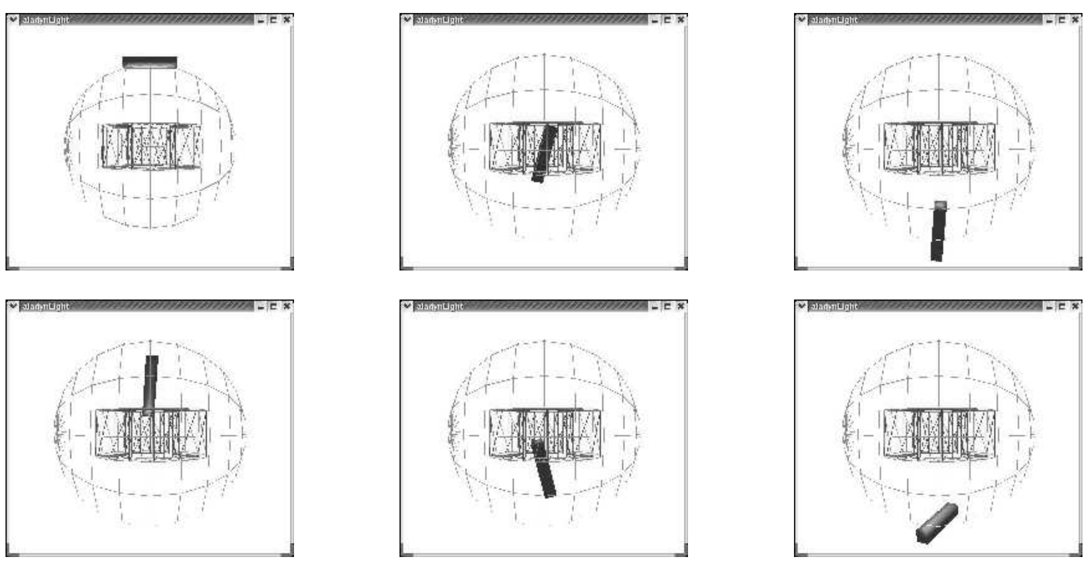


Figure 4. The resulting fall trajectory of the stick object. Its orientation is controlled by using the Bayesian collision detection program.

6.2.3. Computer Aided Surgery

In this context, we have worked in computer aided surgery for the Total Hip Prosthesis (THP) in collaboration with Aesculap-BBraun. The aim of the project is to obtain a CT/MRI-free 3D volume generation of the hip for preoperative planning and navigation, and operative guidance for a normal hip. The approach is to obtain an approximation of the real 3D hip volume of the patient by deforming a nominal 3D hip mesh (Atlas). The deformation consists in driving a set of control points on the hip mesh that will match specific positions provided by 2D radiographic data and 3D echographic data of the patient. Our goal is to use the obtained 3D volume for the preoperative planning and navigation. In the preoperative planning the 3D hip volume will allow the surgeon to select the prosthesis type(size and form) and position. The position will be for a normal hip rang of motion and to avoid prosthesis collision. The 3D volume will be used to guide the surgeon in the prosthesis implantation providing the 3D position and orientation of the patient's hip and the surgical tools.

First evaluations have been made obtaining the 3D coordinates of a "saw bone model" with the "orthopilot system" of Aesculap-BBraun. The deformation have been made using the 2D coordinates of the corresponding radiographic data and the 3D echographic data. The error was calculated between the real 3D coordinates of the sawbone and the deformed hip mesh. We have obtained a mean error of about $1mm$ for the 3D obtained hip volume. Currently work aims at improving accuracy of the 3D obtained hip volume (more specially in the acetabular region), and at completing the experimental validations (Fig. 5).

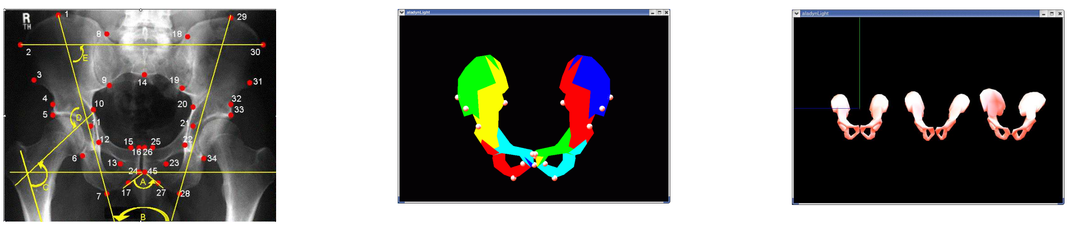


Figure 5. CT/MRI free hip volume generation for a computer aided system of total hip prosthesis (PTH). (a) Personalized hip mesh of the patient obtained from 2D radiographical data and 3D echographical data by the deformation of a hip mesh. (b) The deformation consist in driving a set of control points on a hip mesh that will match the patient proportions. (c) Obtained volume of the patient by the deformation (c).

6.3. Motion planning and Autonomous Navigation in the physical world

6.3.1. Safe Navigation Using Bayesian Programming

Participants: Cédric Pradalier, Jorge Hermosillo, Christophe Braillon, Carla Koike, Pierre Bessière, Christian Laugier.

Two methods developed last year were integrated together this year: On the first hand, we used Bayesian programming to design and develop an efficient and reliable reactive obstacle avoidance system. On the second hand, we developed and experimented the integration of localization and mapping, path planning and trajectory execution. This year, in collaboration with the SED service of INRIA Rhône-Alpes, we integrated obstacle avoidance in our trajectory execution module. This integration stressed the fact that the control law using the CyCab flatness property is very sensitive to perturbations. So, using again Bayesian programming, we had to design a trajectory tracking behaviour that can be used alternatively when flat control law is not reliable any longer. This work has been published in the ICRA'04 conference [33], and a more complete version of the paper has been accepted for publication in the Robotic And Autonomous System journal [74].

Autonomous behavior is also possible whithout mapping, and in this direction a programming framework based on the Bayesian paradigm was proposed in [38] for conception and development of an autonomous

Figure 6. An experimental setting showing the reactive execution of a pre-planned trajectory among pedestrians.

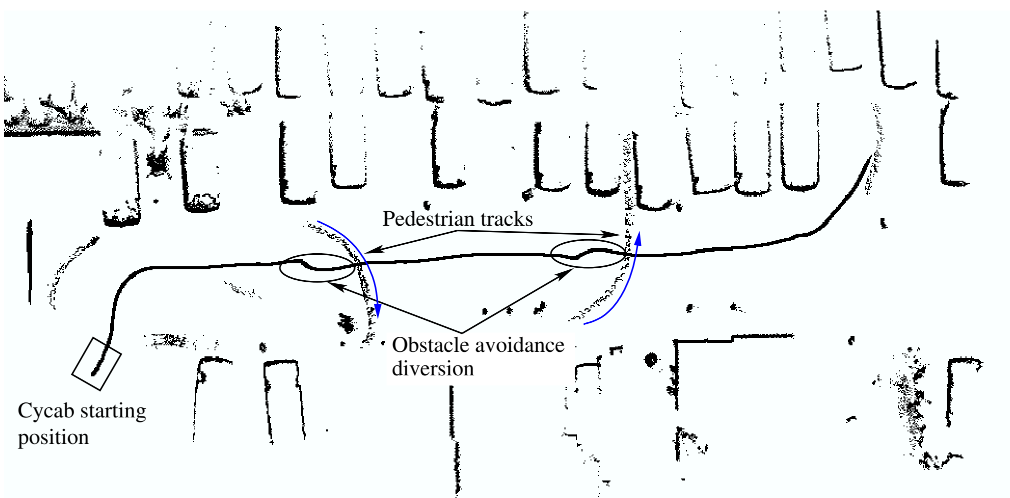


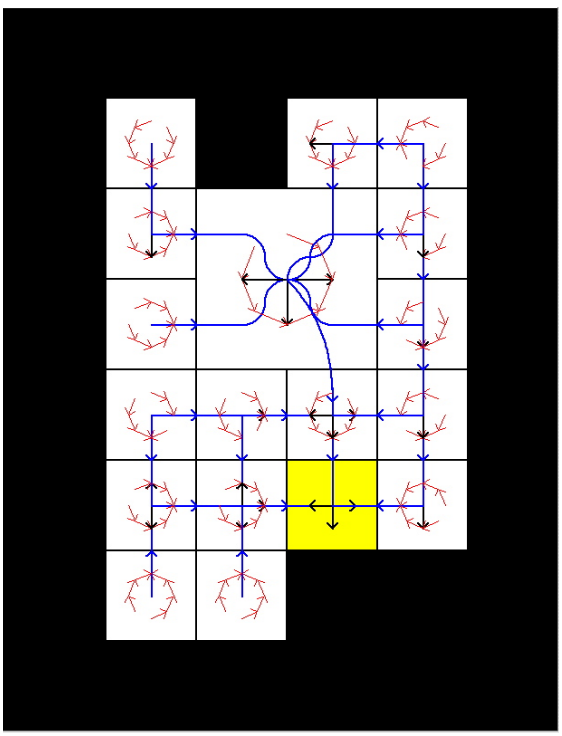
Figure 7. Executed trajectory among static obstacles and moving pedestrians.

behavior for a mobile robot evolving in an unmodified environment. This framework assumes a desired behavior is specified and in order to deal with resulting complexity under limited resources, a general structure based on cascading Bayes Filters is described, applying some insights of natural systems. Some specific questions are addressed, as the role of attention in perception and how action selection influences perception tuning. Practical implementation of this for an animal-like behavior is under development and the reactive obstacle avoidance method presented above is employed in order to achieve safe execution of infered motor commands.

6.3.2. Markov Decision Process-based Navigation

Participants: Olivier Aycard, Julien Burlet, Thierry Fraichard.

The purpose of this research work is to study how the Markov Decision Process Theory can be used to robustify mobile robot navigation. To reach a given goal, a mobile robot computes a motion plan first, (*ie* a sequence of actions that will take it to its goal), and then executes it. Markov Decision Processes (MDPs) have been successfully used to solve these two problems. Such approaches use a graph representation of the robot's state space and their main advantage is that they provide a theoretical framework to deal with the uncertainties related to the robot's motor and perceptive actions during both planning and execution stages. Unfortunately, their algorithm complexity is exponential in the number of edges of the graph which limits their application to complex problems.



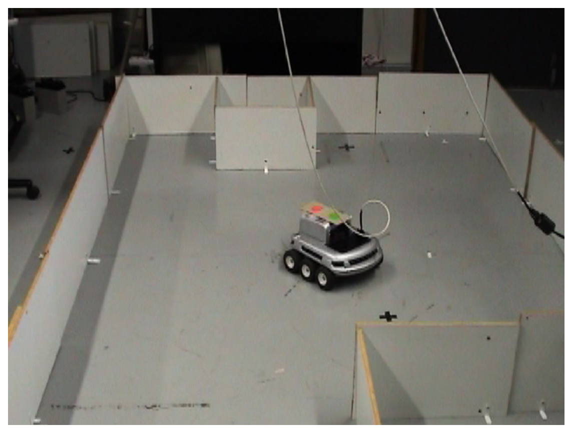


Figure 8. (Left) Example of computed motion strategy. (Right) The Koala robot used to validate our MDP-based navigation approach (right).

Our approach is to address this complexity issue by reducing the number of states through aggregation techniques. We have proposed a MDP-based planning method that uses a hierarchical representation of the robot's state space (based on a quadtree decomposition of the environment). Besides, the actions used better integrate the kinematic constraints of a wheeled mobile robot. These two features yield a motion planner more efficient and better suited to plan robust motion strategies [20].

In 2004, we have focussed on the execution stage. An execution scheme based upon Markov Localisation [59] has been defined and validated experimentally. Central in this validation is the transition function (that encodes the uncertainties related to the robot actions), and the sensors' model: a learning procedure using the real robot and its sensors have been defined and experiments with a Koala mobile platform has demonstrated the robustness of the whole navigation approach (Fig. 8). A paper presenting these results has been submitted to the IEEE Int. Conf. on Robotics and Automation 2005.

6.3.3. Autonomous Navigation based on Real-time optic flow computation

Participants: Cédric Pradalier, Christophe Braillon.

To navigate in open environments, that is to say where there is a lot of moving obstacles (pedestrians, bicycles, cars, ...), we need to detect obstacles (moving or not) and to estimate their state (position, speed, ...). Actually, today's techniques do not allow to measure obstacles motion.

That is why in this work we proposed a new method to compute obstacles position and speed. To be applied to a real robot in dynamic environments we have a real-time constraint.

In a first part, we proposed a new method to compute optical flow in real-time that allows to evaluate a confidence measure. It has been experimentally shown that this algorithm works at the frame rate of 15-30 Hz, and is auto-adaptative to various scene conditions.

Figure 9. Result of optical flow computation

In a second part, we have proposed an obstacle detection technique based on the optical flow. We use it to compute the real motion of the obstacles in the image, and to extract them by comparing their optical flows to the optical flow on the ground. By extracting the obstacles, and knowing their optical flows, we can compute their position and speed.

Experiments have been performed on the Cycab platform on top of which is fixed a stereo camera (only one of the two cameras have been used).

An paper about this work has been submitted to ICRA 2005. Current work (Christophe Braillon's PhD thesis) focus on navigation in open and dynamic environments, using optical flow data combined with some other sensing data and a priori knowledge.

6.3.4. Iterative Partial Motion Planning

Participants: Thierry Fraichard, Stéphane Petti.

When placed in a dynamic environment, *ie* an environment with moving objects, a robotic system cannot stand still since it might be collided by one of the moving objects. In such a framework, a real-time constraint is imposed upon the navigation or motion planning system of the robot considered: it has a limited time only to determine its future course of action. The time available is a function of what is called the *dynamicity* of the environment which is directly related to the speed of both the moving objects and the robotic system. Previous works dealing with robotic systems placed in dynamic environments fall into three families:

1. *Motion planning approaches* wherein a complete motion to the goal is computed [62][61][65]. Unfortunately, the intrinsic complexity of motion planning restricts the use of this kind of approach to simple robotic systems only and environments with low dynamicity.
2. *Reactive approaches* wherein the action for the next time-step only is computed [55][71]. Such approaches do verify the real-time constraint. Unfortunately, their lack of lookahead raises the convergence and safety issues. In other words, what guarantee do the robot have to ever reach the goal and to never find itself in a critical situation?
3. As a partial answer to the convergence and safety issues, *extended reactive approaches* have been proposed wherein the reactive scheme is extended over a few time-steps [50][72].

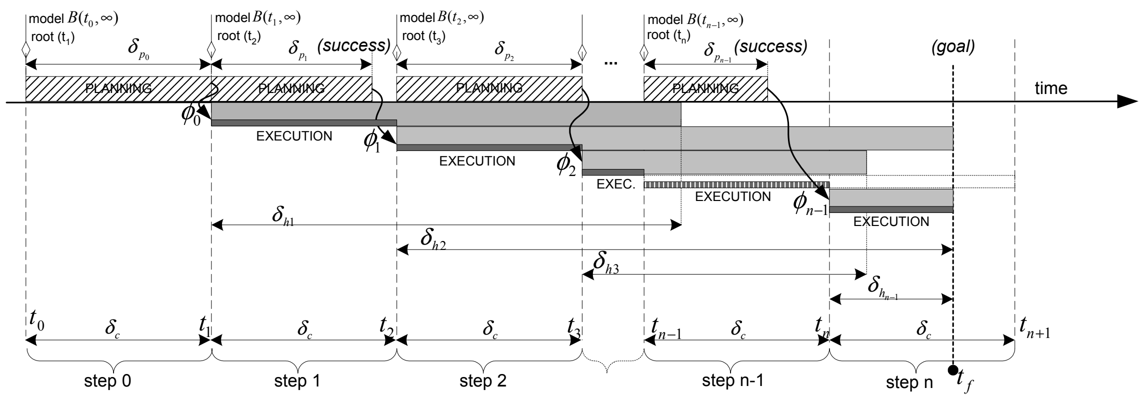


Figure 10. The Iterative Partial Motion Planning cycle. At each time step δ_c, a new predicted model of the environment is built and a partial motion is computed.

Our own answer to the problem at hand is the *partial motion planning approach*. It is similar to an extended reactive approach in the sense that only a partial motion is computed. However, instead of extending a reactive approach over a few time-steps only, it is proposed instead to use randomised motion planning techniques so as to benefit from the advantages of such techniques and to carry out the planning effort as far as possible in the future given the time available. Of course, since only a partial motion is computed, it is necessary to iterate the partial motion planning process until the goal is reached. Accordingly, the whole approach is named *Iterative Partial Motion Planning* (IPMP). Fig. 10 depicts the IPMP cycle.

As a matter of fact, the iterative nature of IPMP is doubly required when the robotic system at hand is placed in a uncertain dynamic environment, *ie* an environment for which everything is not known in advance (in particular, the future behaviour of the moving objects). Motion planning means reasoning about the future. When the future is unknown, one has to resort to predictions, predictions whose validity duration is limited in most cases. An iterative planning scheme permits to take into account the unexpected changes of the environment by updating the predictions at a given frequency (which is also determined by the environment dynamicity)..

Like the reactive and extended reactive approaches, IPMP has to address the convergence and safety issues. As far as the second question is concerned, the unrealistic convergence conditions established in [70] leave little hope (it is hardly surprising if the system is placed in an environment with no a priori information about the moving obstacles). The safety issue is more important and we would like some guarantee that the system never finds itself in a critical situation. To address this safety issue, we have been exploring two different solutions: the first one relying upon the concept of *Inevitable Collision States* and the second one upon the concept of *Non Linear Velocity Obstacles* (*cf* sections 6.3.5 and 6.3.6 respectively).

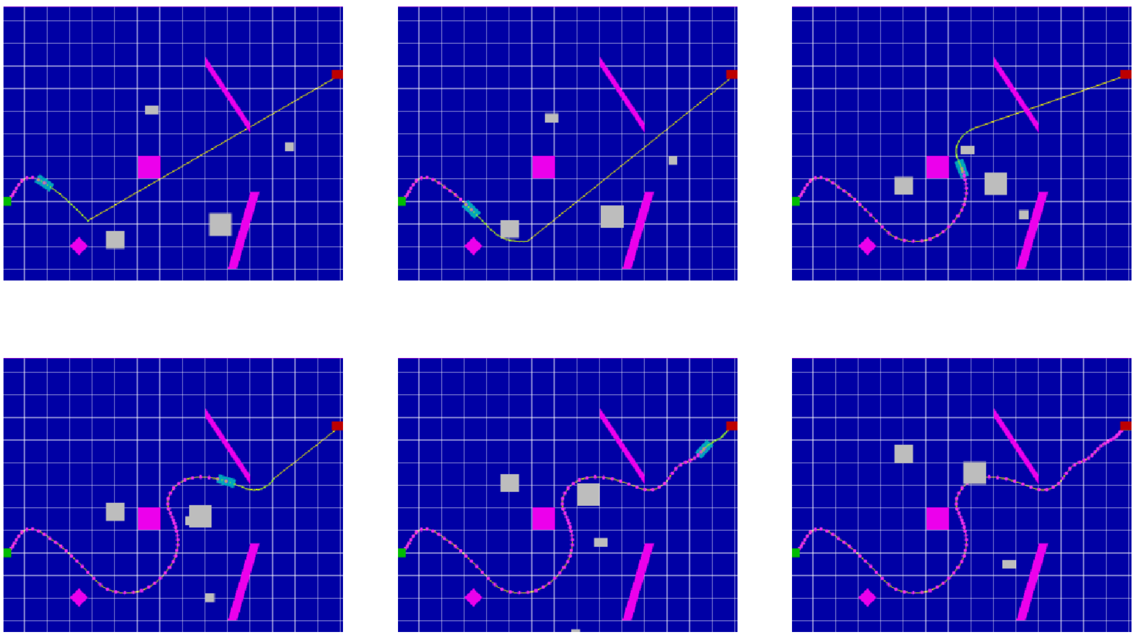


Figure 11. IPMP for a car-like vehicle.

In 2004, a complete prototype of IPMP using the Inevitable Collision States has been implemented and tested for a car-like vehicle (Fig. 11). This work yielded a paper that has been submitted to the IEEE Int. Conf. on Robotics and Automation 2005. In 2005, it is planned to plug the IPMP module on a Cycab experimental vehicle. To do so, the coupling between IPMP and the control level of the Cycab will be studied (Ph.D topic of Stéphane Petti). Live experiments should validate the whole approach.

6.3.5. Inevitable Collision States

Participants: Thierry Fraichard, Stéphane Petti.

In 2002, we introduced the novel concept of *inevitable collision states* (ICS). In general, an ICS for a given robotic system can be defined as a state for which, no matter what the future trajectory followed by the system is, a collision eventually occurs with an obstacle of the environment.

An inevitable collision state takes into account the dynamics of both the robotic system and the obstacles, fixed or moving. This very general concept can therefore be useful both for navigation and motion planning purposes (for its own safety, a robotic system should never find itself in an inevitable collision state).

To illustrate the interest of this concept, it was applied in 2002 to a problem of *safe motion planning* for a robotic system subject to sensing constraints in a partially known environment (*ie* that may contain unexpected obstacles) [49]. In safe motion planning, the issue is to compute motions for which it is guaranteed that, no matter what happens at execution time, the robotic system never finds itself in a situation where there is no way for it to avoid collision with an unexpected obstacle.

While 2003 was dedicated to further the exploration of the ICS concept by demonstrating a number of properties are fundamental for their characterisation [60]. 2004 was mostly spent studying the use of the ICS concept to guarantee safety within the IPMP scheme. We have established that a partial trajectory is not within ICS iff it is collision-free and its final state is not an ICS. This simplifying property has permitted to improve the performance of IPMP, it is presented in a paper that has been submitted to the IEEE Int. Conf. on Robotics and Automation 2005.

6.3.6. Non Linear Velocity Obstacles

Participants: Thierry Fraichard, Frédéric Large, Christian Laugier, Alejandro Dizan Vasquez Govea.

Work on the NLVO paradigm (Non-Linear Velocity-Obstacles) has been initiated in 2001 [75], while looking for a way to improve the decision process of a robot (service robot, intelligent transportation system, virtual character...) moving at high speeds in a partially unknown environment amidst static and mobile objects. The NLVO concept is inspired from the V-obstacle concept. It aims to compute at the same time, the time to collision for all admissible movements of the robot. This information allows a fast estimation of the risk of collision associated with any feasible movement of a robot [67]. This information is a high level representation of the environment in the velocity space of the robot. Contrary to non classical representations, one can stress that such an approach does not loose any possible solutions and takes into account the dynamics of the world.

Two navigation methods have been derived from the NLVO: the first method is reactive, it computes only the next move of the robot: It is more suitable for fast changing environments like a crowd, but may cause the robot to be blocked at some points. The second method aims at avoiding this drawback by building a complete trajectory to the goal. The solution is searched in a tree, iteratively built so that the planning can be suspended at any time to return an intermediate result. This ensures a certain reactivity of the robot, needed for its safety. NLVO are used to expand the tree while the branches to explore are chosen by a heuristic function aiming at optimising the travelling time. The computed trajectories are safe (due to NLVO). They also limit the cases that prevent the robot from reaching its goal, remain coherent between two successive decisions of the robot and stay away from unpredicted objects (thanks to the algorithm used to update the tree).

Computing a NLVO requires a priori knowledge about the future behaviour of the moving objects. In 2004, we have worked on the coupling between the NLVO reactive approach and our moving objects' future motion prediction function [37][36] (*cf* section 6.1.3).

6.4. Probabilistic Inference and Decision

6.4.1. Bayesian Robot Programming

6.4.1.1. Perceptual Servoing on a Sensori-Motor Trajectory

Participants: Cédric Pradalier, Pierre Bessière, Christian Laugier.

Part of our work this year consisted in developing a perceptual servoing on a sensori-motor trajectory. We call "sensori-motor trajectory" a trajectory, which instead of being described as sequence of robot configuration or position, is described as a sequence of exteroceptive perceptions (sensors) associated with proprioceptive perceptions (motors). Our perceptual servoing consists in being able to follow such a trajectory, starting from any configuration in its neighbourhood, going backward or forward, and being able to divert from the trajectory for obstacle avoidance. This task has been addressed in the Bayesian framework, and decomposed in four subtasks: error estimation (i.e. relative localization), trajectory tracking, obstacle avoidance and online estimation of the observation consistency with respect to the localization hypotheses. Successful experimentations were performed, in simulation and on the real robot on the car park of INRIA Rhône-Alpes, showing the validity of the approach. This work has been published in ICRA'04[32] and ISER'04[31]. A more complete article, based on the results presented in C. Pradalier's PhD thesis has been submitted to IEEE transation on robotics.

6.4.1.2. Information Selection and Reactive Behaviors

Participants: Pierre Dangauthier, Carla Koike, Olivier Aycard, Anne Spalanzani, Pierre Bessière.

Information sensed by a robot evolving in a real environment is both too large and uncertain for being easily exploited by the navigation function and the related reactive behaviors.

The first problem is to extract relevant information for the task that the robot is currently performing. Usually this extraction is done by a human programmer who, for instance, decides that proximity sensors are relevant for an obstacle avoidance behavior. But a really autonomous robot should be able to discover that kind of information, which is called "preliminary knowledge" in our bayesian programming framework. Some results have been obtained using methods based on feature selection to determine relevant sensors for a tracking task [57].

This year we applied these technics to auto-supervised learning, a compromise between supervised and completely unsupervised learning, consisting in relying on previous knowledge to acquire new skills [56].

On top of that, we developed a genetic algorithm framework for learning another kind of prior knowledge ("parametrical forms"). This was done considering that animals got their prior knowledge by natural selection. The main idea is to define an entropy driven evolution. This work leads to the implementation of several visual behaviors on the BIBA robot.

The second problem consists in combining several behaviors inspired by biology, in order to perform robustly a variety of tasks. Some interesting results using Bayesian programming have been obtained and experimented on the BIBA robot (for obstacle avoidance and homing strategies) [66]. In relation to reactive behavior, a programming framework based on the Bayesian paradigm was proposed in [38] for conception and development of an autonomous behavior for a mobile robot evolving in an unmodified environment. In order to deal with complexity of desired behavior under limited resources, a general structure based on cascading Bayes Filters is described, applying some insights of natural systems. Questions as attention in perception and action selection influences in perception tuning are addressed, and practical implementation of the framework proposed are in execution. Once motor commands are infered, the reactive obstacle avoidance method presented above is employed in order to achieve safe execution of commands.

6.4.2. Learning Bayesian Behaviors

Participants: Ronan Le Hy, Pierre Bessière.

Bayesian programming techniques used in robotics can be applied to synthetic characters such as those in video games (see figure 12). Both game play and development methodologies can benefit from the learning techniques that arise naturally from these bayesian models.

We have pursued work on developing bayesian programs for behaviour selection and execution for video game characters. Previous results (See [68] for a synthesis on using bayesian programs to execute and learn automata-like behaviours.) have shown that these techniques match or exceed the capabilities of common methods used to control characters. We are now focusing on learning behaviours by demonstration, which includes developing methods to identify human playing behaviours [15].

Figure 12. Learning platform using the Unreal Tournament game

6.4.3. Models and Tools for Bayesian Inference

Participants: Juan-Manuel Ahuactzin Larios, Pierre Bessière, Emmanuel Mazer, Kamel Mekhnacha, Olivier Aycard, Manuel Yguel.

6.4.3.1. New Algorithms for Inference

Two new components have been integrated in the inference algorithms of ProBT Bayesian Inference Engine (BIE): (i) an *expectation maximization* algorithm and (ii) a method for estimating probability distributions of discrete variables by using the *entropy maximization principle*.

Learning using incomplete data is a central issue in Bayesian reasoning. Indeed, some variables of the model may be unobserved and or/some value are missing for another set of variables.

The EM algorithm (Expectation-Maximization) is a general-purpose algorithm used to learn (estimate) model parameters using incomplete data. The idea behind the EM algorithm is intuitive and natural and it has been formulated and applied to a variety of problems. The basic idea of EM is to associate with the given incomplete-data problem, a complete-data problem for which Maximum Likelihood (ML) (or Maximum a posteriori (MAP)) estimation is computationally more tractable.

The EM algorithm consists in reformulating the incomplete-data problem in terms of this more easily solved complete-data problem. The E-step consists in producing data for the complete-data problem, using the observed data set of the incomplete-data problem and the current value of the parameters. The complete-data is then used to fit the free parameters (by maximizing the Likelihood or the data).

Given a probabilistic model, using the EM algorithm to learn the free parameters of its distributions consists in estimating the joint distribution over all variables of the model using the observed data on a subset of them. Suppose, for example, that we are interested in estimating the distribution of a given variable X as a mixture of Gaussians. Given the number (n) of the kernels (Gaussians) of the mixture, the problem is to estimate the distribution of the class variable C and the n mean and variance values of the corresponding Gaussians. In other words, we have to estimate the joint distribution $P(C)P(X|C)$ where $P(C)$ is a probability table over C and, for each value c of C, $P(X|c)$ is a Gaussian distribution.

In the ProBT BIE, the E-step is simply considered as an inference problem consisting in constructing the probability table $P(C|x)$ over C for each observed value x of X. In the M-step, the incomplete-data (x) is replaced by n complete-data $(c1, x), .., (cn, x)$ weighted by the corresponding probability values $P(C = c1) \quad P(C = Cn)$. This complete-data set is then used to estimate the gaussians $G1(X) \quad Gn(X)$. This estimation is made easy thanks to the ProBT complete-data learning module (estimation of histograms, 1d and nd-gaussians,)

The algorithm of *entropy maximization* calculus was integrated in the ProBT BIE as an optimization problem. The ProBT API allows the observable encoding. This scheme is particularly useful when the constraints specification is preferred to probability distributions specification.

6.4.3.2. ProBT Parallel Implementation

In order to respond to computationally intensive ProBT applications exceeding the computing power of a sequential machine, we are currently developing a parallel version of the ProBT BIE. The parallel version is designed in collaboration with the APACHE project. Two specialized environments for parallel probability calculus will be included in ProBT:

- **Symmetric Multiprocessors (SMP)/ Thread computing.** In this environment 2 to 64 processor in a single computer share all the resources (memory, bus, I/O system) to run the ProBT BIE. Each processor handles a specific part of the probability calculus. Once these calculus are finished the partial results are recovered by the master processor who returns the final result.
- **Cluster computing.** In this environment a copy of the ProBT BIE runs on each of the workstations (nodes) conforming the cluster. Each node handles a specific part of the probability calculus. In addition, each of the nodes can be a single or multiprocessor system (SMP). The set of nodes work together as a single high-speed computer. The advantage with respect to other parallel computer architectures is that a cluster uses standard technology accessible at lower cost.

The ProBT API is the same for sequential or parallel computing. That is, a program specified in the ProBT API doesn't change. Just an additional initialization call function is required for the parallel environments (SMP or cluster).

6.4.3.3. ProBT Experimental Data Learning Module

Learning from data is a central issue when using Bayesian methods. This learning may concern the estimation of the free parameters of probability distributions of a Bayesian model, and/or the dependencies between the variables of the model.

For the first problem (i.e. distributions free parameters estimation), numerous classes allowing to learn standard probability distributions have been developed this year.

Future work in this project will concern the second problem (i.e. learning variables dependencies possibly under a set of constraints).

7. Contracts and Grants with Industry

7.1. Contracts and Grants Involving Industry

- CyberCars [August 2001-July 2004]
  European project IST-2000-28487 CyberCars, "Cybernetic Cars for a New Transportation System in the Cities", (http://www.cybercars.org).
  The goals of this project are the development and experimentation of new techniques of transport. These techniques are based on the use of individual and automatical vehicles which circulate in the streets of the cities or private sites instead of using of a private car complementary to public transport. The CyberCars consortium includes 14 partners coming from industry and public research. The contribution of *e-Motion* in CyberCars relates to driving automation.
- Carsense [January 2000-December 2003]
  European project IST 1999-12224 CarSense, “Sensing of Car Environment at Low Speed Driving” (http://www.carsense.org). A consortium of 12 european car manufacturers, suppliers and research institutes are together under the head of the CARSENSE programme. This programme, sponsored by the EC shall develop a sensor system, that shall give sufficient information on the car environment at low speeds in order to allow low speed driving. This project includes european industrials from car industry (Renault, BMW, Lucas Varity, Thomson Detexys, Ibeo, etc.) and research institutes (Inria, Inrets, Livic). *e-Motion* is in charge of the data fusion subject.
- Profusion [2004-2008]
  European project, PreVENT Programme (Preventive and Active Safety Applications) Profusion, “Project for Robust and Optimized Perception by Sensor Data Fusion”
  The first phase of ProFusion was a short six months project, which began February 1st and ended July 31st. It was the first stage of a horizontal activity within IP PReVENT, that aimed at: establishing a forum including representatives of specified vertical subprojects for exchanges on topics related to sensors and sensor data fusion, circulating, feeding back and synthesizing information exchanged, and exploiting the outcome from these exchanges to specify and propose one or more new horizontal subproject(s) with a technical content focussed on original research work of common interest in these fields, leading to tangible results.
  These six months were a period of intensive work, which included the organization of three workshops regrouping partners coming from industry and public research. ProFusion first phase was a success (congratulation from the PReVENT core group). The ProFusion second phase should start at the beginning of 2005.

- Puvame [October 2003-September 2005]
  National project, Predit Programme Puvame “Protection des Usagers Vulnérables par alarme et Manoeuvre d’Evitement”
  An important number of accidents between vulnerable road users and moving traffic could be avoided by improving the abilities of visibility and estimation of the situation by the driver, and by putting in action an alarm system addressed to the driver and the road user in danger. This project will contribute to reduce the number of accidents of this type, by developing the principal following functionalities: (1) Improvement of the abilities of perception of the driver in close and average distance environments by dated fusion; (2) Detection and estimation of the dangerous situations, by analyzing current data relating on the "behavior of the driver" and to the estimation result of the "dangerosity" of the operations in progress; (3) Activation of alert actions associated to vehicle and vulnerable users; (4) Integration and experiments on vehicles and preliminary study on bus and/or trams. INRIA Rhône-Alpes is coordinator of the project. The partners are: *e-Motion* project (Inria Rhône-Alpes; Christian Laugier, Olivier Aycard, Thierry Fraichard, Anne Spalanzani) and Imara project (Inria Rocquencourt; Michel Parent), Ecole des Mines de Paris (EMP), INRETS, Intempora, Probayes, Robosoft, Connex.
- Mobivip [October 2003-September 2005]
  National project, Predit Programme Mobivip “Véhicules Individuels Publics pour la Mobilité en centre ville”
  The project gathers 5 laboratories and 7 industrials to implement, evaluate and demonstrate the NTIC impact on a new mobility service. More precisely, the goals are to implement:(1) a transportation service base on free-use vehicles, (2) a multimodal information system, (3) a toolbox for integration in global management policy at downtown scale.
- ARCOS [June 2003-December 2004]
  National project, Predit Programme Arcos“Action de Recherche pour une COnduite Sécurisée”
  Within the PREDIT programme, the ARCOS project has for aim to find a global solution for the system “ vehicle-driver-infrastructure’ ’, in order to contribute to the improvement of the road safety(with the goal to reduce by 30% the accidents!). *e-Motion* is in charge of the research subject “ Information synthesis and commands development”. This project includes many french laboratories working in the field of vehicles and road (ENSMP, INRETS/LIVIC, SUPELEC, UTC...) as well as the largest french car manufacturers (PSA and Renault).
- Kelkoo [October 2003-March 2004]
  Industrial project, ProBayes start-up.
  Kelkoo the european leader of price comparison on Internet proposes to its customers a service making it possible to compare the offers on the market. In order to propose increasingly precise information on the products Kelkoo creates a data base of these products. A very important function is the association of offers with the products of Kelkoo data base. This function already exists but requires many adjustments to take into account the inaccuracies of the different offers suggested. The aim of the collaboration of Kelkoo with INRIA is the validation of the use of an inference engine based on bayesian probabilities to carry out a matcher able "to learn" and to improve the results of the matching offer/product without requiring long and expensive adjustments.
- AMIB-E [June 2002-June 2004]
  This RNTL collaboration project (called AMIB-E) between INRIA and two industrial partners,(n amely: MGE UPS SYSTEMS and TEAMLOG) aims at building a Bayesian preventive maintenance tool.
  The first prototype concerns the modeling and the simulation of the wearing process of the UPS capacitance component.Its aim is to warn the system maintainer that this component have to be replaced when the probability to get this component out of order(after a given period time)

reaches a given threshold value.The next phase in this project will concern modeling more complex UPSsystems. To make this modeling task easier, a user-friendly graphic interface will be developed. Its aim is to allow graphical specification of the probabilistic model followed by an automatic generation of the corresponding ProBT code.

- Visteo [May 2000-July 2004]
  This project has started in May 2000 for a 24 months-length. This project is supported by the PRIAMM national programme. The intial partners of the project was GETRIS images, the Sharp project (now *e-Motion*) and the Movi project of INRIA Rhône-Alpes. After one year of work, the project has been "frozen" until the GETRIS images company has been replaced in 2003 by a new one: XL-Studio located in Lyon, with an extension of the project for 18 months. The aim of this project is to develop a set of software tools allowing the set up of "virtual studios" physically realistic and including interactions between the virtual character and the human displayed in the studio. The project was succefully terminated at the end of July 2004, with a transfert of the *VisteoPhysic* library to the XL-Studio company.

8. Other Grants and Activities

8.1. Other funding, public, European and Regional

- Robea "Speech-gifted android" [2002-2004]
  This project gathers three partners : ICP-IMAG, University of Texas At Austin, and Inria *e-Motion*. Its objectives are the study and modelling of perception, production and learning mechanisms, in order to improve our understanding of the word and the language, and to open new ways for their automatic treatment.
- Robea "Bayesian models for motion generation" [2003-2005]
  This project involves three partners : Inria *e-Motion* (leader), Inria *Evasion*, and Irisa *Siames*. The objective is to propose new forms of interaction between human and data-processing systems. The synthetic worlds created and managed by these systems can be populated by human actors and virtual actors controlled by computers. The approach that we propose consists in equipping the virtual entities in these environments with an autonomy of movement and action, as well as adaptability and reactive abilities to certain situations.
- Robea "Parknav" [October 2002- September 2005]
  This project gathers five partners : Inria *e-Motion* (leader), Inria *Movi* and *Prima*, Irisa *Vista*, and LAAS Toulouse. The goal of the project is to automate the driving of a vehicle moving amidst mobile obstacles (other vehicles, pedestrians) on a site equipped with a camera-based perception system. A joint demonstration integrating both the perception and the planning levels is scheduled in the last phase of the project. It will take place on the Inria Rhône-Alpes parking site which is currently being equipped with a multiple-camera perception system and will involve Cycab experimental vehicles.
- IST-FET "Biba" [November 2001- November 2005]
  European project IST-2001-32115 "Bayesian Inspired Brain and Artefacts". The project involves five partners : Inria *e-Motion* (coordinator), University College of London (Gatsby Unit), University College of Cambridge (Physiology lab), Collège de France (Laboratory of Physiology of Perception and Action, A. Berthoz), Ecole Polytechnique Fédérale de Lausanne (Autonomous Systems Lab, R. Siegwart), and the Massachusetts Institute of Technology (Non Linear Systems Lab, JJ. Slotine). The twin technological and scientific goals of the *BIBA* project are the followings :(1) to reconsider in the light of Bayesian probabilistic reasoning our methodology, models,algorithms and techniques for building artefacts for the "real world"; (2) to provide a firm Bayesian basis for understanding how biological systems use probabilistic logic to exploit the statistical properties of their environments.

The project is organised along 3 axes of research and development: (1) Neural basis of probabilistic inference; (2) New probabilistic models and algorithms for perception and action; (3) New probabilistic methodology and techniques for artefact conception and development.

- France-Mexico “Navdyn” [October 2003- October 2005]
  The *NavDyn* project is a joint *Lafmi*[5] project between *e-Motion* and the Center for Intelligent System (CSI) of the Mexican Technological Institute of Monterrey (ITESM). The goal of the project is to develop basic tehnologies for the “Autonomous Navigation in Dynamic Environments”. CSI Itesm is in charge of the vision part of the project (detection and tracking of moving objects using an off-board pan-tilt video camera), whereas *e-Motion* is in charge of the autonomous motion part (taking into account moving objects with unknown future behaviour). The midterm evaluation that took place in November 2003 was successful and the project was prolongated.
- France-Singapore “Neurophysiology and robotics” [June 2004- June 2008]
  This CNRS-PICS project involving the Collège de France (LPPA), INRIA *e-Motion*, the University of Singapore (NUS), and the *IPAL* joint CNRS-NUS laboratory in Singapore. The objective is to study some aspects of the physiology of human vision, and to try to develop robotics models inspired from biological systems. An application of this research we will be to control a wheelchair from natural human control channels. This research involves a co-directed PhD student located in singapore.
- France-Korea “SafeMove” [April 2004- April 2006]
  The *SafeMove* project is a joint project in the scope of the France-Korea STAR programme. It aims at conducting common research activities in the area of Intelligent Transportation Systems (ITS) and Automated Guided Vehicles (AGV). The proposed project combines three research groups (two French: Inria and Lasmea Clermont-Ferrand, and one Korean: Sungkyunkwan University) having complementary skills and expertise to conduct research in the area of ITS and AGV, particularly focused on models and algorithms allowing for safe autonomous navigation in dynamic environments (like those found in a urban context).

8.2. International Collaborations

8.2.1. Pacific and South Asia

8.2.1.1. Collaboration with Japan

Since October 1997, *e-Motion* has a collaboration with Riken Institute in Tokyo in the multi-robots systems field . Crossed visits have occured for the last three years. In 2002, Thierry Fraichard spent 4 months in Riken Institute and Igor Paromtchik spent 4 months at INRIA. Informal exchanges are still going on.

8.2.1.2. Collaboration with Singapore

The common laboratory, named *Intelligent Vehicle Lab*, between Nanyang Technological University of Singapore (NTU) and Inria has started in November 1998, in the framework of the scientific collaboration in the field of autonomous vehicles. This collaboration has brought: (a) an important number of crossed visits and stays (one week to several months) of researchers, (b) Singaporeans students in Inria (level undergraduate to graduate), and (c) organization of workshops (1999-2002). in 2003, Julien Diard has been a Postdoc student in NUS and a co-directed PhD (Brice Rebsamen) will begin in January 2004 in NUS. In addition, a PICS CNRS project has been accepted in 2004 with NUS and LPPA(College de France, Alain Berthoz).

8.2.2. North America

8.2.2.1. Collaboration with Vancouver University (Canada)

Collaboration in the field of dextral handling begun with the stay of professor K. Gupta at Inria Rhone-Alpes in 1995, continued by several long stays of Moez Cherif and Juan Manuel Ahuactzin, and with crossed visits. Common publications has been done in 2000 and 2001. Informal exchanges are still going on.

[5]Lafmi is a France-Mexico laboratory in computer sciences

8.2.2.2. Collaboration with California University of Berkeley (USA)

In the framework of the programme France-Berkeley a one-year collaboration in the field of dynamic simulation has been settled in 2000-2001. This collaboration continued in 2002 within the framework of a new project on the simulators of surgery supported by the France-Berkeley funds (with the team S. Sastry). Several crossed stays of researchers took place. David Bellot is now a Postdoc student in Berkeley.

8.2.2.3. Collaboration with Stanford University

The study of force-feedback in virtual environments and the non linear elastic deformations have been the research subjects of this collaboration with the Center of Advanced Technology in Surgery of Stanford University. Several researchers crossed stays also took place (in particular: Remis Balaniuk).

8.2.3. Central and South America

8.2.3.1. Collaboration with Mexico

The thematic network "Image et Robotique" has been implemented from the French-Mexican symposium in Computer Sciences and Control (JFMIA'99) which has been held in Mexico in March 1999. The main goal of this network is to promote and increase the french-mexican cooperations in Image and Robotics in scientific, academic and industrial fields. This network has been effectively settled in 2000. It supports a yearly school, students exchange and crossed visits.

The NavDyn project between *e-Motion* and "Centro de Sistemas Inteligente", Itesm, Monterrey lasts from October 2002 to September 2004. This project supported by the French-Mexican Lab in Computer Sciences (LAFMI) studies the field of vehicle navigation in dynamic environment.

9. Dissemination

9.1. Dissemination

The dissemination of results and the active participation to international scientific events (see bibliography) are two essential activities of the *e-Motion* project-team.

Some members of *e-Motion* participates to some international committees:

- C. Laugier is a member of the steering-advisory committee of IEEE/RSJ IROS (Intelligent Robots and Systems) international conference since 1997. He is also a member of the advisory committee of the ICARCV International conference on Control, Automation, Robotics and Vision.
- C. Laugier is a member of the steering committee of the European Network EURON.
- C. Laugier is a member of the following national scientific committees : French-Korean committee of the French Ministry of Foreign Affairs, National programme in Robotics ROBEA, CNRS RTP17 on Robotics, and inter-ministerial PREDIT group 9 on new technologies for transport.
- T. Fraichard was member of the program committee of the Iberoamerican Conf. on Artificial Intelligence, Puebla (MX), November 2004, and the IEEE-RSJ Int. Conf. on Intelligent Robots and Systems. Sendai (JP), October 2004.
- T. Fraichard was a member of the organization committes of the First Korea-France Symposium on Dependable Robotic Navigation, Seoul (KR), October 2004.
- T. Fraichard and P. Bessière are regurlarly members of the programme committees of the ICRA and IROS conferences.

9.2. Academic Teachings

In addition to ponctual academic lectures, the members of *e-Motion* have tought the following lectures:

- Lecture “Motion planning”, LAFMI Summer School on Image and Robotics: Sophia Antipolis (FR) [June 2004]. *Teacher: T. Fraichard.*
- Lecture “Robotic”s, Summer school "Automatic Control for Production Systems", Grenoble [June 2001, July 2002, June 2004]. *Teacher: T. Fraichard.*
- Lecture “Motion planning”, Master "Mathématics, Informatics", "Image, Vision, Robotics" option (ex DEA), INPG-UJF, Grenoble. *Teacher: T. Fraichard.*
- Lecture “Outils probabilistes et statistiques pour l’Informatique”: (every year): Licence d’Informatique de l’Université Joseph Fourier 3^{e} année, Grenoble, (FR). *Teacher: O. Aycard*.
- Lecture “Inférence et apprentissage bayesien”: (every year): Ecole Polytechnique de Grenoble, Grenoble, (FR). *Teacher: O. Aycard*.
- Lecture “Inférence et apprentissage bayesien": (every year): Master d’Informatique de l’Université Joseph Fourier 1re année, Grenoble, (FR). *Teacher: O. Aycard*.
- Lecture “Bayesian robot programming”: (every year): Master 2^{e} année “Imagerie, Vision, Robotique” de l’INPG, Grenoble, (FR). *Teachers: P. Bessière and O. Aycard*.
- Lecture “Bayesian robot programming”: France-Mexico Summer school on “Image and Robotics” (every year). *Teachers: O. Aycard and P. Bessière*.
- Tutorial on “Autonomous mobile robots in real environments”: Singapore, May 2004. *Teachers: C. Laugier and O. Aycard*.
- Lecture “Introduction to robotics and current research issues” (every year): France-Mexico Summer school on “Image and Robotics” (every year). *Teacher: C. Laugier.*
- Lecture “Robotics and motion autonomy” (every year): DEA “Imagerie, Vision, Robotique” INPG, Grenoble, (FR). *Teacher: C. Laugier*.
- Lecture “Basic tools and models for Robotics” (every year): Cnam Grenoble. *Teachers: C. Laugier and J. Troccaz.*

9.3. Conference and workshop committees, invited conferences

Some members of *e-Motion* participates to various international conferences committees and to the organization of summer schools :

- C. Laugier and J.M. Ahuactzin participated to the organizing committee of the 2004 summer school on “Image and Robotics” at Inria Sophia-Antipolis (June 2004).
- C. Laugier participate every year to the organization committees of the major international conference on Robotics, in particular : IEEE International Conference on Robotics and Automation (ICRA), IEEE/RSJ Intenational Conference on Intelligent Robots and Systems (IROS), International Conference on Field and Service Robotics (FSR). He was general chair of IROS’97, Regional programm chair of IROS’00, Programme chair of IROS’02.
- T. Fraichard and P. Bessière are regurlarly members of the programme committees of the IEEE ICRA and IEEE/RSJ IROS conferences.
- Invited session organisation, Autonomous vehicles in dynamic environments, Int. Conf. on Control, Automation, Robotics and Vision, Kunming (CN), December 2004, by Th. Fraichard.

Some members of the *e-Motion* project-team have also given invited talks adressed to a larger public :

- C. Laugier gave a talk at the conference SRG’04 in Singapore (May 2004) on “Will future robots really share our living space ?”.
- Seminar “TIC et mobilité”, Antibes (June 2004). Talk on “Tools for automated driving” by Th. Fraichard.
- Colloquium of the French Navigation Institute, Paris (March 2004). Talk on “Intelligent transport systems” by Th. Fraichard.

10. Bibliography

Major publications by the team in recent years

[1] O. AYCARD, J.-F. MARI, R. WASHINGTON. *Learning to automatically detect features for mobile robots using second-order Hidden Markov Models*, in "International Journal of Advanced Robotic Systems", vol. 1, n° 4, Dec 2004, p. 231–245, http://emotion.inrialpes.fr/bibemotion/2004/AMW04.

[2] C. COUÉ, C. PRADALIER, C. LAUGIER. *Bayesian Programming for Multi-Target Tracking : an Automotive Application*, in "Proc. of the Int. Conference on Field and Service Robotics, Lake Yamanaka (JP)", July 2003.

[3] T. FRAICHARD, H. ASAMA. *Inevitable Collision States. A Step Towards Safer Robots?*, in "Advanced Robotics", vol. 18, n° 10, 2004, p. 1001-1024.

[4] T. FRAICHARD. *Trajectory planning in a dynamic workspace: a ‘state-time’ approach*, in "Advanced Robotics", vol. 13, n° 1, 1999, p. 75–94.

[5] C. LAUGIER, T. FRAICHARD. *Decisional architectures for motion autonomy*, in "Intelligent vehicle technologies", L. VLACIC, F. HARASHIMA, M. PARENT (editors)., chap. 11, Butterworth-Heinemann, 2001, p. 333-391.

[6] C. LAUGIER, P. GARNIER, T. FRAICHARD, I. PAROMTCHIK, A. SCHEUER. *Motion Planning and Sensor-Guided Manœuvre Generation for an Autonomous Vehicle*, in "Field and Service Robotics", A. ZELINSKY (editor)., Springer, 1998, p. 60–67.

[7] E. MAZER, P. BESSIÈRE, J.-M. AHUACTZIN. *The Ariadne's Clew Algorithm*, in "Journ. of Artificial Intelligence Research", vol. 9, July-December 1998, p. 295–316.

[8] K. MEKHNACHA, E. MAZER, P. BESSIÈRE. *A Robotic CAD system using a Bayesian framework*, in "Proc. of the IEEE-RSJ Int. Conf. on Intelligent Robots and Systems, Takamatsu (JP)", November 2000.

[9] C. PRADALIER, J. HERMOSILLO, C. KOIKE, C. BRAILLON, P. BESSIÈRE, C. LAUGIER. *The CyCab: a Car-like Robot Navigating Autonomously and Safely among Pedestrians*, in "Robotics Autonomous Systems", In Press.

Doctoral dissertations and Habilitation theses

[10] C. PRADALIER. *Navigation intentionnelle d'un robot mobile*, Thèse de doctorat, Inst. Nat. Polytechnique de Grenoble, Grenoble (FR), September 2004.

[11] K. SUNDARAJ. *Simulation Dynamique en Temps-Réel et Interaction 3D de Tissu Biologique: Application aux Simulateurs Médicaux*, Thèse de doctorat, Inst. Nat. Polytechnique de Grenoble, Grenoble (FR), January 2004.

Articles in referred journals and book chapters

[12] D. BELLOT, R. SIEGWART, P. BESSIÈRE, A. TAPUS, C. COUE, J. DIARD. *Bayesian Modeling and Reasoning for Real World Robotics: Basics and Examples*, in "Embodied Artificial Intelligence, Int. Seminar, Dagstuhl (DE), July 7-11, 2003", F. IIDA, R. PFEIFER, L. STEELS, Y. KUNIYOSHI (editors)., Lecture Notes in Computer Science, vol. 3139, Springer-Verlag, 2004, p. 186–201.

[13] T. FRAICHARD, A. SCHEUER. *From Reeds and Shepp's to Continuous-Curvature Paths*, in "IEEE Trans. on Robotics and Automation", vol. 20, n^o 6, December 2004.

[14] J. HERMOSILLO, C. PRADALIER, S. SEKHAVAT, C. LAUGIER. *Autonomous Navigation of a Bi-steerable Car : Experimental Issues*, in "Machine Intelligence and Robotic Control Journal", To appear, 2004.

[15] R. LE HY, A. ARRIGONI, P. BESSIÈRE, O. LEBELTEL. *Teaching Bayesian Behaviours to Video Game Characters*, in "Robotics and Autonomous Systems", vol. 47, 2004, p. 177–185.

[16] O. LEBELTEL, P. BESSIÈRE, J. DIARD, E. MAZER. *Bayesian Robot Programming*, in "Advanced Robotics", vol. 16, n^o 1, 2004, p. 49–79.

[17] O. LEBELTEL, P. BESSIÈRE, J. DIARD, E. MAZER. *Programmation bayésienne des robots*, in "Revue d'Intelligence Artificielle", vol. 18, n^o 2, 2004, p. 261–298.

[18] C. PRADALIER, S. SEKHAVAT. *Simultaneous Localization and Mapping using the Geometric Projection Filter and Correspondence Graph Matching*, in "Advanced Robotics", To appear, 2004.

[19] K. SUNDARAJ, C. LAUGIER, F. B. DE-CASSON. *Towards a Complete Intra-Operative CT-Free Navigation System for Arthroscopy Anterior Cruciate Ligament Reconstruction*, in "Int. Journal of Human Friendly Welfare Robotic Systems", vol. 5, 2004.

Publications in Conferences and Workshops

[20] J. BURLET, O. AYCARD, T. FRAICHARD. *Robust Motion Planning using Markov Decision Processes and Quadtree Decomposition*, in "Proc. of the IEEE Int. Conf. on Robotics and Automation, New Orleans, LA (US)", April 2004, p. 2820–2825.

[21] P. DANGAUTHIER, A. SPALANZANI, P. BESSIÈRE. *Statistical methods and genetic algorithms for prior knowledge selection.*, in "Actes du congrès francophone de Reconnaissance des Formes et Intelligence Artificielle, Toulouse (FR)", In French, Submitted, January 2004.

[22] J. DIARD, P. BESSIÈRE, E. MAZER. *A theoretical comparison of probabilistic and biomimetic models of mobile robot navigation*, in "Proceedings of the IEEE International Conference on Robotics and Automation (ICRA04), New Orleans, LA, USA", 2004, p. 933–938.

[23] J. DIARD, P. BESSIÈRE, E. MAZER. *Hierarchies of probabilistic models of navigation: the Bayesian Map and the Abstraction operator*, in "Proceedings of the IEEE International Conference on Robotics and Automation (ICRA04), New Orleans, LA, USA", 2004, p. 3837–3842.

[24] J. DIARD, P. PANAGIOTAKI, A. BERTHOZ, P. BESSIÈRE. *Modeling human spatial navigation components and their relationship using Bayesian sensori-motor schemas*, in "Proceedings of the 12th World Congress of Psychophysiology", 2004.

[25] M. GOMEZ, J. AHUACTZIN. *Using Generalized Cylinders for Collision Detection in Robotics*, in "Proc. of the Int. Symp. on Robotics and Automation, Queretaro (MX)", August 2004.

[26] M. KAIS, S. DAUVILLIER, A. DE LA FORTELLE, I. MASAKI, C. LAUGIER. *Towards Outdoor Localization Using GIS, Vision System andStochastic Error Propagation*, in "Proc. of the Int. Conf. on Autonomous Robots and Agents, Palmerston North (NZ)", December 2004.

[27] M. KAIS, S. MORIN, A. DE LA FORTELLE, C. LAUGIER. *Geometrical Model to Drive Vision Systems with Error Propagation*, in "Proc. of the Int. Conf. on Control, Automation, Robotics and Vision, Kunming (CN)", December 2004.

[28] F. LARGE, D. VASQUEZ, T. FRAICHARD, C. LAUGIER. *Avoiding Cars and Pedestrians using V-Obstacles and Motion Prediction*, in "Proc. of the IEEE Intelligent Vehicle Symp., Pisa (IT)", Poster session, June 2004.

[29] O. LEFEBVRE, F. LAMIRAUX, C. PRADALIER, T. FRAICHARD. *Obstacles Avoidance for Car-Like Robots. Integration And Experimentation on Two Robots*, in "Proc. of the IEEE Int. Conf. on Robotics and Automation, New Orleans, LA (US)", April 2004, p. 4277–4282.

[30] P. PANAGIOTAKI, J. DIARD, A. LEHMANN, A. BERTHOZ. *Hierarchical Cognitive Mechanisms of Memory encoding during Spatial Navigation on Humans: Psychophysical Studies with Virtual Reality*, in "Proceedings of the 12th World Congress of Psychophysiology", 2004.

[31] C. PRADALIER, P. BESSIÈRE, C. LAUGIER. *Driving On A Known Sensori-Motor Trajectory With A Car-like Robot*, in "Proc. of the Int. Symp. on Experimental Robotics, Singapore (SG)", June 2004.

[32] C. PRADALIER, P. BESSIÈRE. *Perceptual navigation around a sensori-motor trajectory*, in "Proc. of the IEEE Int. Conf. on Robotics and Automation, New Orleans, LA (US)", April 2004.

[33] C. PRADALIER, J. HERMOSILLO, K. KOIKE, C. BRAILLON, P. BESSIÈRE, C. LAUGIER. *An Autonomous Car-Like Robot Navigating Safely Among Pedestrians*, in "Proc. of the IEEE Int. Conf. on Robotics and Automation, New Orleans, LA (US)", April 2004.

[34] K. SUNDARAJ, C. LAUGIER, F. B. DE CASSON. *Towards a Complete Intra-Operative CT-Free Navigation System for Arthroscopy Anterior Cruciate Ligament Reconstruction*, in "Proc. of the Int. Symposium on Medical Simulation, Cambridge, MA (US)", June 2004.

[35] D. VASQUEZ, T. FRAICHARD. *Motion Prediction for Moving Objects: a Statistical Approach*, in "Proc. of the IEEE Int. Conf. on Robotics and Automation, New Orleans, LA (US)", April 2004, p. 3931–3936.

[36] D. VASQUEZ, F. LARGE, T. FRAICHARD, C. LAUGIER. *High-Speed Autonomous Navigation with Motion Prediction for Unknown Moving Obstacles*, in "Proc. of the IEEE-RSJ Int. Conf. on Intelligent Robots and Systems, Sendai (JP)", October 2004, p. 82–87.

[37] D. VASQUEZ, F. LARGE, T. FRAICHARD, C. LAUGIER. *Moving Obstacles' Motion Prediction for Autonomous Navigation*, in "Proc. of the Int. Conf. on Control, Automation, Robotics and Vision, Kunming, China", December 2004.

Internal Reports

[38] BIBA. *european project deliverable 16*, confidential, European Community, "Information Society Technologies" Programme, 2004.

[39] C. BRAILLON. *Utilisation du flux optique pour le détection d'obstacles et la navigation*, Mémoire de Diplôme d'Etudes Approfondies, Inst. Nat. Polytechnique de Grenoble, June 2004.

[40] J. BURLET. *Déplacements sous incertitudes d'un robot mobile*, Mémoire de Diplôme d'Etudes Approfondies, Inst. Nat. Polytechnique de Grenoble, June 2004.

[41] F. COLAS, P. BESSIÈRE, J. DROULEZ, M. WEXLER. *Human perception of shapes in relative motion.*, Rapport Interne., 2004.

[42] J. DIARD, P. PANAGIOTAKI, A. BERTHOZ, P. BESSIÈRE. *The Bayesian Map: a probabilistic and hierarchical model of navigation*, BIBA european project deliverable 15, section 6.3 "Bayesian Inspired Brain and Artefacts: using probabilistic logic to understand brain function and implement life-like behavioural coordination", European Community, "Information Society Technologies" Programme, 2004.

[43] C. T. M. KEAT. *Car Park Mapping with Simultaneous Localization and Mapping (SLAM)*, Report for DEA/M2R, Institut National Polytechnique Grenoble (INPG), INRIA Rhone Alpes (GRAVIR), September 2004.

[44] R. LEZAMA-MORALES. *Détection probabiliste de collisions*, Mémoire de Diplôme d'Etudes Approfondies, Inst. Nat. Polytechnique de Grenoble, September 2004.

[45] H.-K. ONG. *Real Time Algorithms For Collision Detection Of Deformation Objects: Case Study Of Self-Collision Using AABB Trees — Physical Simulation Using FEM and LEM*, Industrial Attachment Report, Nanyang Technological University, June 2004.

[46] E. SIMONIN. *Carte bayésienne et apprentissage*, Mémoire de Diplôme d'Etudes Approfondies, Inst. Nat. Polytechnique de Grenoble, June 2004.

Bibliography in notes

[47] S. ARULAMPALAM, S. MASKELL, N. GORDON, T. CLAPP. *A Tutorial on Particle Filters for On-line Non-linear/Non-Gaussian Bayesian Tracking*, 2002, http://citeseer.ist.psu.edu/maskell01tutorial.html.

[48] S. BLACKMAN, R. POPOLI. *Design and Analysis of Modern Tracking Systems*, Artech House, 2000.

[49] S. BLONDIN. *Planification de mouvements pour véhicule automatisé en environnement partiellement connu*, Mémoire de Diplôme d'Etudes Approfondies, Inst. Nat. Polytechnique de Grenoble, Grenoble (FR), June 2002.

[50] BROCK, KHATIB. *High Speed Navigation Using the Global Dynamic Window Approach*, in "Proc. Int. Conf. On the Robotics and Automation", 1999.

[51] H. BUI, S. VENKATESH, G. WEST. *Policy recognition in the Abstract Hidden Markov Models*, in "Journal of Artificial Intelligence Research", vol. 17, 2002, p. 451–499, http://citeseer.ist.psu.edu/bui02policy.html.

[52] M. C., K. SUNDARAJ, C. LAUGIER. *Issues in Deformable Virtual Objects Simulation with Force Feedback*, in "Proc. of the IARP Int. Workshop on Human Robot Interfaces, Rome (IT)", November 2002.

[53] C. COUÉ. *Modèle bayésien pour l'analyse multimodale d'environnements dynamiques et encombrés : application à l'assistance à la consuite automobile en milieu urbain.*, Thèse de doctorat, Inst. Nat. Polytechnique de Grenoble, December 2003.

[54] C. COUÉ, C. PRADALIER, C. LAUGIER. *Bayesian Programming for Multi-Target Tracking : an Automotive Application*, in "Proc. of the Int. Conference on Field and Service Robotics, Lake Yamanaka (JP)", July 2003.

[55] W. D. FOX, S. THRUN. *The Dynamic Window Approach to Collision Avoidance*, in "IEEE Robotics and Automation Magazine", vol. 4, 1997, p. 23-33.

[56] P. DANGAUTHIER, P. BESSIÈRE, A. SPALANZANI. *Auto-supervised learning in the Bayesian Programming Framework*, in "ICRA", Submitted, 2005.

[57] P. DANGAUTHIER. *Sélection automatique de variables pertinentes*, Mémoire de Diplôme d'Etudes Approfondies, Inst. Nat. Polytechnique de Grenoble, Grenoble (FR), June 2003.

[58] J. DIARD. *La carte bayésienne : un modèle probabiliste hiérarchique pour la navigation en robotique mobile*, Thèse de doctorat, Inst. Nat. Polytechnique de Grenoble, January 2003.

[59] D. FOX, W. BURGARD, S. THRUN. *Active markov localization for mobile robots*, in "Robotics and Autonomous Systems", 1998.

[60] T. FRAICHARD, H. ASAMA. *Inevitable Collision States. A Step Towards Safer Robots?*, in "Advanced Robotics", To appear, 2005.

[61] T. FRAICHARD. *Dynamic Trajectory Planning with Dynamic Constraints: a 'State-Time Space' Approach*, in "Proc. of the IEEE-RSJ Int. Conf. on Intelligent Robots and Systems, Yokohama (JP)", vol. 2, July 1993, p. 1394–1400.

[62] E. FRAZZOLI, E. FERON, M. DAHLEH. *Real-Time Motion Planning for Agile Autonomous Vehicle*, in "Proc. of the AIAA Conf. on Guidance, Navigation and Control, Denver, CO (US)", August 2000.

[63] B. FRITZKE. *A growing neural gas network learns topologies*, in "Advances in Neural Information Processing Systems 7, Cambridge MA", G. TESAURO, D. S. TOURETZKY, T. K. LEEN (editors)., MIT Press, 1995, p. 625–632.

[64] J. GIBSON. *The perception of visual surfaces.*, in "American Journal of Psychology", vol. 63, n° 3, 1950, p. 367-84.

[65] D. HSU, R. KINDEL, J.-C. LATOMBE, S. ROCK. *Randomized kinodynamic motion planning with moving obstacles*, in "Proc. of the Workshop on the Algorithmic Foundations of Robotics, Hanover, NH (US)", March 2000, p. 233–255.

[66] C. KOIKE, C. PRADALIER, P. BESSIÈRE, E. MAZER. *Proscriptive Bayesian Programming Application for Collision Avoidance*, in "Proc. of the IEEE-RSJ Int. Conf. on Intelligent Robots and Systems, Las vegas, NV (US)", October 2003.

[67] F. LARGE. *Navigation Autonome d'un Robot Mobile en Environnement Dynamique et Incertain*, Thèse de doctorat, Université de Savoie, Chambéry (FR), November 2003.

[68] R. LE HY, A. ARRIGONI, P. BESSIÈRE, O. LEBELTEL. *Teaching Bayesian Behaviours to Videogame Characters*, in "Proc. of IROS'03 Workshop on Robot Programming by Demonstration, Las vegas, NV (US)", October 2003.

[69] J. LORIEUX. *Détection et suivi de véhicules par télémétrie laser en robotique autonome*, Mémoire de Diplôme d'Etudes Approfondies, Inst. Nat. Polytechnique de Grenoble, Grenoble (FR), June 2003.

[70] V. LUMELSKY, S. TIWARI. *Velocity Bounds for Motion Planning in the Presence of Moving Planar Obstacles*, Research Report, n° RL-94004, Univ. of Wisconsin-Madison, Robotics Lab., Madison, WI (US), May 1994.

[71] J. MINGUEZ, L. MONTANO. *Nearness Diagram Navigation. A New Real-Time Collision Avoidance Approach*, in "IEEE/RSJ Int. Conf on Intellingent Robots and Systems, Takamatsu, JP", 2000.

[72] J. MINGUEZ, L. MONTANO, N. SIMÉON, R. ALAMI. *Global Nearness Diagram Navigation*, in "Proc. of the IEEE Int. Conf on Robotics and Automation, Washington DC", 2002.

[73] M. MONTEMERLO, S. THRUN, D. KOLLER, B. WEGBREIT. *FastSLAM: A factored solution to the simultaneous localization and mapping problem*, 2002, http://citeseer.ist.psu.edu/montemerlo02fastslam.html.

[74] C. PRADALIER, J. HERMOSILLO, C. KOIKE, C. BRAILLON, P. BESSIÈRE, C. LAUGIER. *The CyCab: a Car-like Robot Navigating Autonomously and Safely among Pedestrians*, in "Robotics Autonomous Systems", Accepted.

[75] Z. SHILLER, F. LARGE, S. SEKHAVAT. *Motion Planning in Dynamic Environments: Obstacles Moving Along Arbitrary Trajectories*, in "Proc. of the IEEE Int. Conf. on Robotics and Automation, Seoul (KR)", May 2001, p. 3716–3721.

[76] É. SIMONIN, J. DIARD, P. BESSIÈRE. *BBPRM: a behavior-based probabilistic roadmap method*, in "submitted to ICRA 05", 2005.

[77] É. SIMONIN, J. DIARD, P. BESSIÈRE. *Learning Bayesian models of sensorimotor interaction: from random exploration toward the discovery of new behaviors*, in "submitted to ICRA 05", 2005.

[78] J. VAN BOXTEL, M. WEXLER, J. DROULEZ. *Perception of plane orientation from self-generated and passively observed optic flow.*, in "Journal of Vision", vol. 3, n° 5, 2003, p. 318-332, http://journalofvision.org/3/5/1/.