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

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2. Overall Objectives

2.1. Overall Objectives

Keywords: *Automatic learning*, *Automatized motions and actions*, *Bayesian programming*, *Bayesian techniques for perception*, *Biologic inspiration*, *Computational geometry*, *Robotics*, *Space-time reasoning*.

2.1.1. *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 being 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 progress 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:

- *Perception and Multimodal 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 and modelling of living mechanisms*. 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 use and develop our bayesian programming paradigm. We are also adressing in this way, in collaboration with neurophysiologists, the problem of living mechanism modelling such as biological sensori-motors loops or vision based perception of shapes and motions 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 being able to make appropriate decisions from complex and incomplete data and knowledge, 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, 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

- *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.

[3]Advanced Driver Assistance Systems

- *Cycab Simulator and programming toolbox. People involved : Cédric Pradalier, Christophe Braillon, David Raulo, with the participation of the SED team* 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 developers an TCP/IP controllable Cycab, consistent with simulated and real Cycab in term of C++ interface.
- *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 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
- *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 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.
- *Markov models toolbox. People involved : Olivier Aycard.* This toolbox is a C++ library for prototyping applications for interpretation of temporal sequences of noisy data. It is available for Linux and PC Windows (Visual C++). The Markov models toolbox has two main components: (i) a definition of Markov models and learning of its parameters component. This component permits to manually define the topology of a Markov model, and to automatically learns the parameters of the defined model. Original learning algorithms have also been developped to automatically build the topology of the model and estimate its parameters. The result of this part is a set of Markov models, where each model is trained (ie, estimated) to recognize a particular type of temporal sequence of noisy data. (ii) an interpretation component. Its goal is to interpret a temporal sequence of noisy data and to determine the most probable corresponding Markov models. This Markov models toolbox is patented under the french APP patent #IDDN.FR.001.280011.000.S.P.2004.000.10000 and has been used to perform a preliminay study of recognition of behaviours of a car driver in cooperation with TOYOTA and also to interpret sequence of noisy sensor data of mobile robots [35]

6. New Results

6.1. Multimodal and Incremental Modelling of Space and Motion

6.1.1. Simultaneous Localization and Mapping in Changing Environments

Participants: Christopher Tay Meng Keat, Christian Laugier.

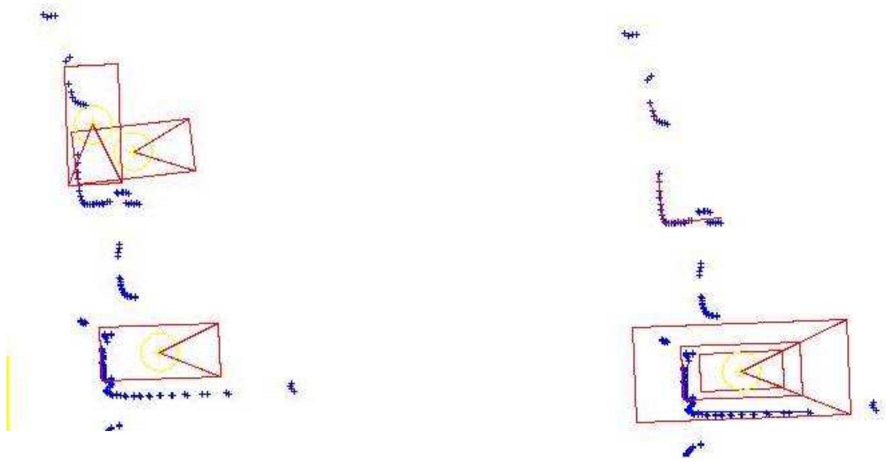


Figure 1. (left) Detected vehicles after first stage filtering. (right) Detected vehicles after second stage filtering

Simultaneous Localization And Mapping (SLAM) is a well known problem in the robotics 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 [63], [51]. To extend our knowledge on this field, we initiated 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 cars, 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 in 2003. What was obtained was a first static extraction of vehicle hypothesis from laser range data which constitutes the first stage of the vehicle hypothesis filtering process. The second objective was achieved in 2004 (C. Tay Meng Keat, [67]). We managed to improve the robustness of the vehicle extraction by performing strict double checking during the second stage of vehicle hypothesis filtering. The method of FastSLAM [61] was chosen to perform the mapping. The results on mapping of the car park by making use of the vehicle hypotheses as landmarks have been published in FSR'05 [24] and IROS'05 [25].

In the course of our research, we have also identified the limitations presented by the laser sensor in the robust identification of vehicles. The next step will be to perform SLAM in dynamic environments, by taking into account moving objects. We envisage the fusion of camera information with laser sensor data. This potentially augments the robustness in terms of the classification of obstacles and the ability to detect moving and static objects. Such information is of importance to SLAM in dynamic environments.

Previously, landmarks in the parking have been recognised by detecting the highly reflective cones installed in the car park [63]. Some preliminary work has been performed concurrently on extracting geometry instead of detecting reflective cones. We are able to extract "naturally" occuring landmarks such as lamp posts and trees found in the environment. The advantage of doing so will be to eliminate the dependence on installing artificial landmarks found in the environment. Such geometrical methods gives relatively frequent false detections. However, our preliminary findings indicate robustness of our mapping algorithn even with the presence of false landmark detections. Figure 2 shows an example of the map reconstructed.

Figure 2. An example of a map reconstructed by using geometrical methods in detecting landmarks

6.1.2. Bayesian Maps

Participants: Julien Diard, Pierre Bessière, Eva Simonin, Estelle Gilet.

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 [46].

We have previously argued [45] 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.

We have pursued the study of the Bayesian Map formalism, in two ways.

The first is a theoretical study of the way Bayesian Maps can be put together, in a way that is a generalisation of classical sensor fusion [18]. In the resulting map, locations are the conjunction of underlying possible locations, which allows for more precise localization and more complex tasks.

The second is an experimental work, concerned with the incremental learning of Bayesian Maps [30]. In previous works [23], we have learned experimentally a Bayesian Map that allowed the Koala robot to navigate (avoid walls, follow walls), based on proximity sensors. Given this map, we have learned a new map based on another sensory modality (light sensing). This new map allows to define new behaviors, like phototaxis and photophobia. Given these two maps, we have then merged them, using a variant of the Superposition operator. In this variant, the robot applies a behavior from one of the map, and learns the experimental probability distribution over the internal variable of the other map. The learned distribution then serves to classify and recognize various environments. We have finally shown how this classification could serve as a basis for learning a map of a higher level of abstraction, that describes the large scale structure of the arena the robot navigated in. Finally, in this experimental part of our work, we have studied the use of the Superposition and Abstraction of Bayesian maps in an experiment involving the control and manipulation, by a robotic arm, of several objects [31].

6.1.3. Adaptative target tracking using Multiple-Model Methods

Participants: Julien Burlet, Olivier Aycard, Christian Laugier, Anne Spalanzani.

To move autonomously in an unknown and dynamic environment, a robot must first perceive the different obstacle on its way. In particular dynamic obstacles, named targets, must be recognized and tracked to permit the robot to avoid them. So, the target tracking is a pre-requisite to address the autonomous motion problem.

In maneuvering target tracking we must deal with motion uncertainty of the target. Indeed, a target could move unpredictly in different ways with different speeds. So it's very difficult to define a model which fits all the possible motion of a target. The multiple-model approach gets around the difficulty due to the model uncertainty by using more that one model. The basic idea is to assume a set M of models as possible candidates of the true mode; run a bank of elemental filters (Kalman filter for example), each based on a unique model in the set; and generate the overall estimates by a process based on the results of these elemental filters. Nevertheless, each mode must be defined *a priori* and a lot of parameters had to be learned or fixed.

After studying the multiple-model approach, we have started to define an adaptative tracking method based on the multiple-model. The principle of the method is to dynamically add or delete modes depending on the motion of the target. The implementation of this method will constitute the major part of our future work.

6.1.4. Moving Objects' Future Motion Prediction

Participants: Thierry Fraichard, Alejandro Dizan Vasquez Govea, Olivier Aycard, 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 [69].

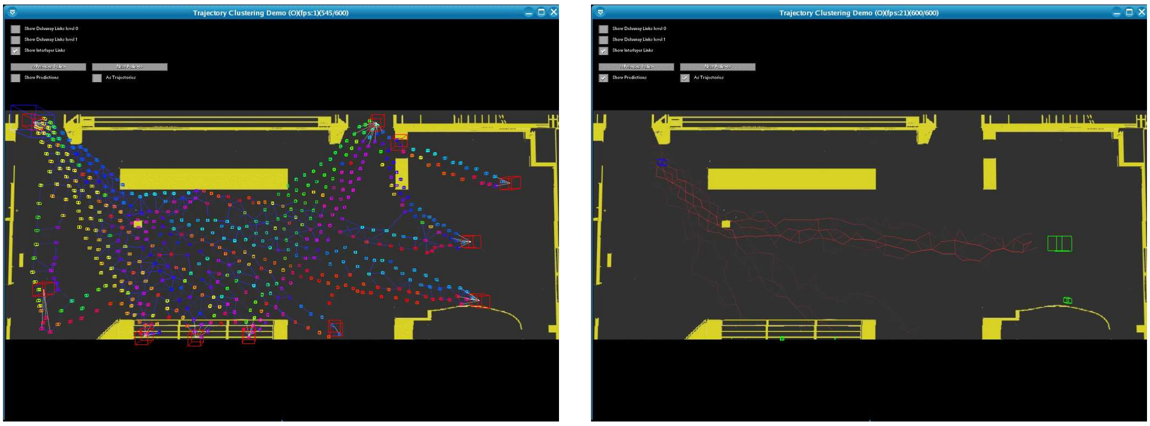


Figure 3. Learning (left): small boxes correspond to the states found by the SOM. Red boxes are high-level goals or policies. Links indicate transitions (bluer is more probable). Prediction (right): the blue box corresponds to the actual object position, green boxes represent the belief about the high level goal (bigger is more probable). Red lines correspond to the predicted trajectories (redder is more probable)

During 2004 and 2005, 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 [49]. One of the main advantages of this approach is that it is adaptive and works on-line (Fig. 3).
- *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 [39]. Thanks to the chosen state representation, it is possible to learn transition probabilities at the same time we are constructing the state representation (Fig. 3).

During 2005, most work has been focused on testing our approach with real data coming from a vision system located in INRIA’s entry hall. The obtained results are very encouraging and are consistent with the ones previously obtained in simulations [26]. Further work has been performed to apply the technique to a parking lot environment simlator that we have developed, early results have shown that the GNG algorithm fails to represent places with very low probability of observing motion (e.g. parking places) so, we have started to experiment with the Grow When Required algorithm [60] which deals better with such situations.

6.1.5. Dynamic Scenes Interpretation by Bayesian Data Fusion

Participants: Manuel Yguel, Olivier Aycard, Christian Laugier.

A prerequisite to a reliable ADAS (Advanced Driving Assistance Systems) in such complex traffic situations is an estimation of the dynamic characteristics of the traffic participants (car, pedestrians, bycicles, etc.), 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 [36] and therefore do not adress urban driving specificities. Numerous methods (JPDA, PMHT, etc.) consider a 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 dimension grid, including 2D-positions and 2D-velocities. We called the corresponding model the *Bayesian Occupancy Filter (BOF)* [43]. 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 [44]. The BOF approach have been improved in 2005 in order to be faster and more robust. Two patents application have been done on this original concept and on the new method as a component of ADAS system. This technology have been partially validated on real data provided by TOYOTA europe, in the scope of a short term contract whose aims were tracking pedestrian with temporary occlusions. Thanks to the good results TOYOTA Europe has decided to establish a long term collaboration with our research team.

In parallel to the previous work we have started to address the problem related to the large amount of data structures which are required for large scale road environments. We have started to develop a new representation using multiscaled time-space representations like wavelets (Fig. 4). The challenge with this new data structure was to make the fusion process available even if the information is compressed in the wavelet space. This technique has been implemented and tested and produces good results [27]. With this framework we have reduced the size of occupancy grids by 80%. Moreover with our experiment the accuracy of the map at different scales seems relevant and it leads in the future to possible multilevel path-planning algorithms.

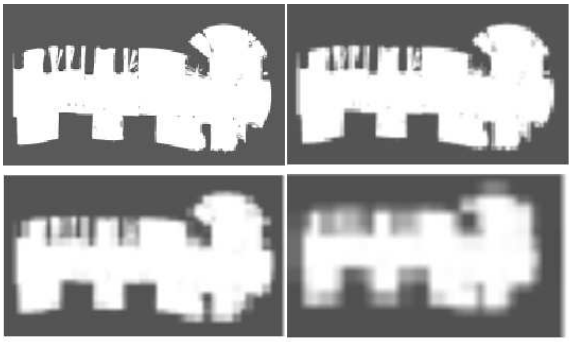


Figure 4. Different scales of the wavelet decomposition of INRIA Rhône-Alpes parking map. The map was constructed with SLAM algorithm by Cycab sensors and the decomposition using a Haar wavelet decomposition

However we have noticed in our experimentation that the smoothness of the sensor models were decisive criteria for the rate of compression in the wavelet occupancy grids. Therefore we have formalized the equations of telemetric sensors for occupancy grids, such as the resulting sensor models is smooth even in two dimensions (Fig. 5). The formalism we have presented is a general one for control the switching of discrete coordinate systems. The algorithm we have presented is exact and leads to anytime precision procedures for any kind of 2D switching of discrete coordinate systems. This framework is useful one because the issue of switching of discrete coordinate systems is fundamental in most of bayesian modelling.

Perspectives: we plan to put both sensor models and wavelet Haar transforms on Graphical Processor Unit (GPU) that are cheap and massively parallel. That enables very fast, accurate and secure fusion and so allows the use of many differents sensors in parallel. We plan to work on the extraction of objects from the grids. And we plan to work on the possibility of tracking objects via other kinds of traking framework using occupancy grids next year.

6.1.6. Perception of Shapes From Motion

Participants: Francis Colas, Pierre Bessière.

Human observers can perceive the three-dimensional structure of their environment using various cues, an important one of which is motion parallax ([50]). The motion of any point's projection on the retina depends both the point's movement in space and on its distance from the eye. Therefore, retinal motion can be used to extract the 3D structure of the environment and the shape of objects, a process known as *structure-from-motion* (SFM). However, since many combinations of 3D structure and motion can lead to the same optic flow, SFM is an ill-posed inverse problem.

It is commonly believed that it is at least partly solved by a constraint called the *rigidity assumption*, the hypothesis that optic flow is due to 3D translations and rotations of a rigid body. This drastically reduces the number of degrees of freedom associated with motion, and it can be shown that under this assumption, both structure and motion can theoretically be recovered from very little optic flow information ([68]). Psychophysical results show that human performance on some SFM tasks is at least broadly consistent with

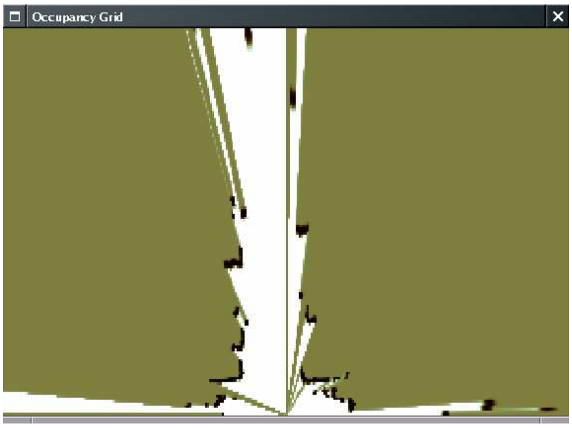


Figure 5. An egocentered occupancy grid, building with a laser range-finder. This view is calculated with a pre-calculated switching coordinate map. The whole 2D image is mapped from the cylindrical point-of-view of the sensor.

predictions based on the rigidity assumption ([72], [54]). Although most of these studies involve an immobile observer, it is known that SFM is also effective when optic flow is generated by the observer's own head movement about a stationary 3D scene ([65]). Until recently, it has been thought that 3D shapes perceived in subject-motion SFM are the same as those perceived in object-motion SFM, as long as the optic flow is the same ([73], [65]). However, in some cases this turns out to be false: even when optic flow is kept constant, the observer's movement does influence perceived 3D shape [47].

We had already begun to propose a Bayesian model of the perception of planes from optic flow. The Bayesian programming framework was chosen for its capacity to deal with inverse and ill-posed problems. The symmetry of Bayes' rule allows for a similar specification of inverse and direct problems and probability distributions can represent the multiple solutions of an ill-posed problem. The model we proposed conciliates both rigidity and stationarity assumptions in probabilistic form: the perceived flow is assumed more probably rigid, and the object motion, more probably small.

This year, we extended our model to take into account eye motion. This allow us to test our model with pursuit tasks. We validated this extension with the experimental results from Naji and Freeman ([62]). Their experiment is about the perception of a sinusoidally curved surface undergoing lateral translation while being pursued with the eyes by the subject. In this condition, they found few depth reversal (misperception of the sign of the curvature). However, the same optic flow observed without pursuit leads to prevalent depth reversals.

More specifically, three conditions were tested. Object translation without pusuit (condition A), object rotation (condition B) and object translation with pursuit (condition C). Condition A and C share the same object motion whereas conditions B and C share the optic flow. The task was to decide the phase of the corrugation, that is, if the top of the object was farther or nearer than the middle of the object. Figure 6 shows the proportion of top-far answer with respect to the strength of the stimulus.

We have shown that the ambiguity of their curved object is similar to the ambiguity of the optic flow of the plane. We have simulated plane objects in the same three conditions and we have built a bayesian decision model. The results of the model are shown figure 7. The results in condition B can be explained by the rigidity in small field of vision. Our model explains the difference between condition A and C by the greater stationarity of more slanted percepts in condition C.

This work is detailed in Colas' PhD thesis to be defended in january ([42]) and is undergoing publication ([28]).

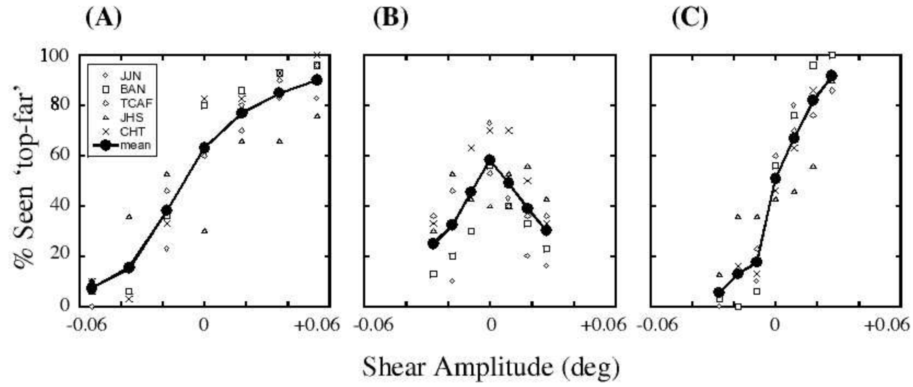


Figure 6. Experimental results from ref. [62]. The graphs show the percentage of top-far answer with respect to stimulus strength. The stimlus strength is the signed amplitude of the corrugation. A positive stimulus is top-far whereas negative stimuli are top-near. Perception in condition B (object rotation) does not disambiguate the sign of the stimulus as is attested by the symmetry of the answers. Perception in conditions A (object translation without pursuit) and C (object translation with pursuit) allow for a disambiguation and condition C lead to a more precise estimation of the sign of the stimulus.

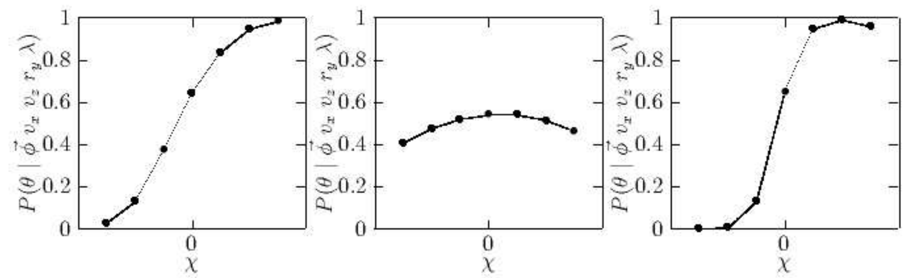


Figure 7. Results of the model of the perception of planes. Results in condition B show the same ambiguity as the experimental results. Condition A and C are appropriately perceived by the model. Results in condition C are more precise than condition A.

6.2. Computed Aided Surgery

Participants: Miriam Amavizca, Christian Laugier, Emmanuel Mazer.

Remark : This research topic is related to the previous Sharp team project. It will be ended at the end of 2005 (with the Miriam Amavizca's ph-D). This year, a paper related to our previous work on the dynamic and interactive simulation applied to an echographic medical procedure, has been published in a medical journal ([15]). See activity report of 2004 at http://emotion.inrialpes.fr.

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. The deformation consists in driving a set of control points on the hip mesh, in order to match specific positions (atlas hip) 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 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 of the surgical tools.

In 2005, we have made two main contributions to this approach :

- a study of the exploitable characteristics of hip and femur for 3D model reconstruction,
- a methodology for 3D hip volume reconstruction using minimally invasive imagining techniques: a single radiographic image (2D data) and a few echographic images (3D data).

We have defined the set of the selected caracteristic hip points as an "probabilistic atlas" of the hip. This atlas is then used for the above mentionned 3D hip volume reconstruction method. The method consists of three main stages : (i) data acquisition of the radiographic and echographic images of the patient hip, (ii) inference of the hip atlas of the patient and (iii) 3D hip volume reconstruction using a mesh deformation mechanism exploiting the data given by the atlas and by the medical images. These stages pose different problems related to the representation of the generic atlas of the hip, to the inference process, and to the radiographic and echographic data processing. To solve this problematic we have used Bayesian techniques. This is detailed in the thesis of Miriam Amavizca [12].

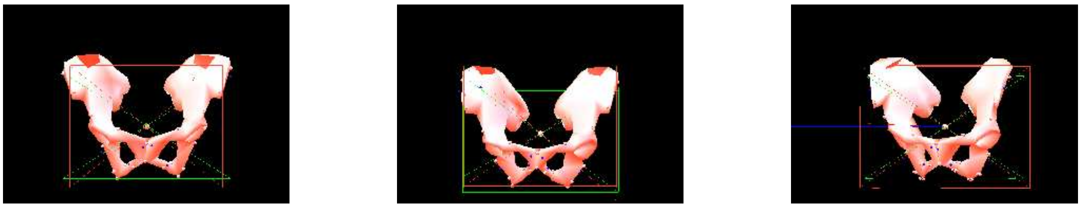


Figure 8. 3D hip models reconstruction from radiographic and echographic incomplete images.

6.3. Motion planning and Autonomous Navigation in the physical world

6.3.1. Robot's navigation in static known indoor environments

Participants: Olivier Aycard, Julien Burlet, Thierry Fraichard.

To reach a given goal, a mobile robot first computes a motion plan (*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. We have defined in a first part of our work [40], a MDP-based planning method that uses a hierarchic representation of the robot's state space (based on a quadtree decomposition of the environment). The second part of our work, published in 2005 [16] deals with the execution stage. It defines an approach based on Markov localization and focuses on experimental aspects. Experimental results carried out with a real robot demonstrate the robustness of the whole navigation approach.

6.3.2. Cycab simulator

Participants: Christophe Braillon, Cédric Pradalier, David Raulo.

In order to perform pre-test and to provide help for Cycab developers, a Cycab simulator has been developed. 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 2005, and Master IVR at ENSIMAG Grenoble 2005-06). The simulator project (called CycabTK) has been published on the INRIA Forge (gforge.inria.fr). This publication aims at federating Cycab users by providing a generic toolkit. The Cycab simulator will be tested in several INRIA Research unit (IRISA, LORIA, Rocquencourt) and in LASMEA laboratory (Université Blaise Pascal, Clermont Ferrand).

A camera simulator has been recently developped, to do so the environment has been modeled in 3D (the former version was 2D) and the sensors' simulators have been improved (the 3D model of the environment allows simulate more precisely the sensors behaviours).

Figure 9. 3D view of the simulator of the INRIA Rhône-Alpes car park

6.3.3. Autonomous navigation based on visual features

Participants: Christophe Braillon, Amaury Nègre.

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 the position and speed of te obstacles. 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.

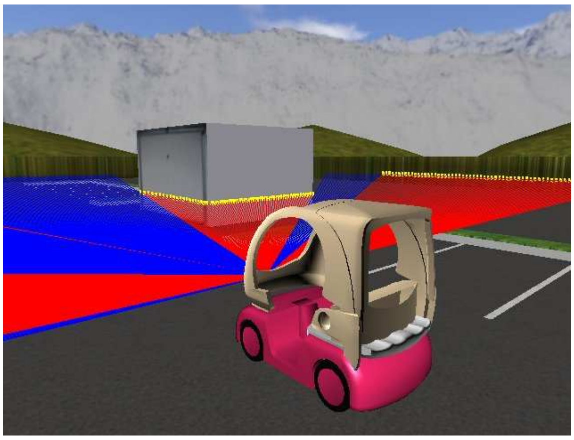


Figure 10. Sick laser range finder simulator

Figure 11. Video sequence used to compute optical flow and find the ground

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.

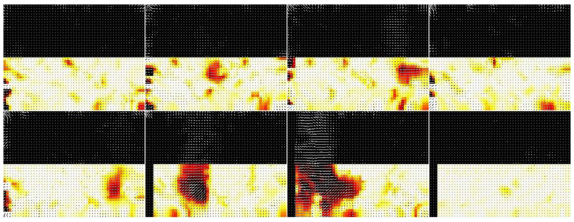
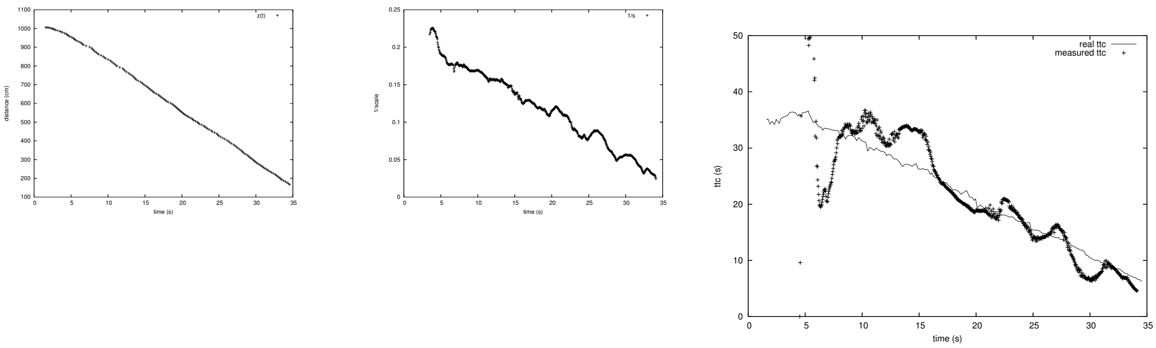


Figure 12. Result of optical flow computation and floor segmentation. Black corresponds to probability 0 for the considered pixel to be the floor, red $\frac{1}{3}$, yellow $\frac{2}{3}$ and white 1

At the same time, methods based on intrinsic scale variation have been developed. It consists in detecting objects using natural interest points and ridges. These objects are tracked to measure their intrinsic scale variation, which we have shown to be in linear relation to the time to collision.



(a) Distance measured by the laser range finder

(b) Inverse of the scale evaluated by intrinsic scale

(c) TTC obtained by the laser range finder and computed with TTC from intrinsic scale.

Figure 13. Test with a constant speed. The distance (13) and the inverse size (13) of the obstacle are linear. The time-to colision is shown on (13), after a period of initialisation, the two curve are fairly near.

Experiments have been performed on the Cycab platform on front of which is fixed a color camera.

Papers about these works have been submitted to ICRA 2006. Current work (Christophe Braillon's and Amaury Nègre's PhD thesis) focus on navigation in open and dynamic environments, using optical flow data and intrinsic scale variation 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 a situation like this, 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 dynamics of both the moving objects and the robotic system.

Oddly enough, this real-time constraint is in most cases overlooked by previous works addressing motion planning in dynamic environments. Few recent works do attempt to take it into account however [52], [38]. These works rely upon the most efficient motion planning techniques available today, namely the randomised techniques such as the Probabilistic Roadmap [53] or the Rapidly Exploring Random Tree [56]. The average running time of these motion planning algorithms is low enough so that they can be used like reactive systems.

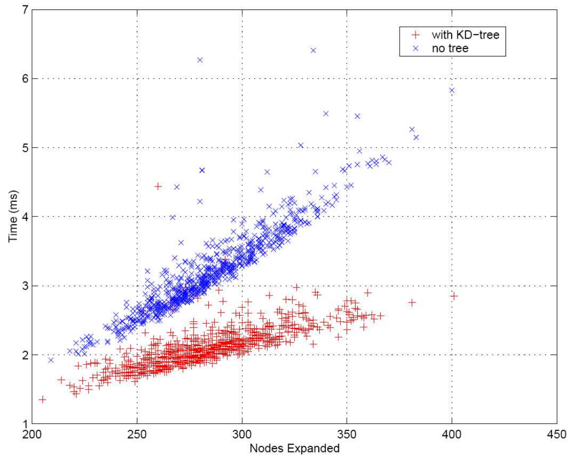


Figure 14. Running time versus number of nodes developed of two "Rapidly-Exploring Random Tree"-based randomised motion planners [38].

This type of approach is very interesting since it offers an answer to the lack of lookahead of the regular reactive approaches. It also seems to address the real-time constraint mentioned earlier (provided the running time is low enough). Unfortunately, the real-time constraint is not satisfied since the running time of a randomised technique cannot be upper bounded (notice the outliers in Fig. 14).

Given the intrinsic complexity of motion planning in dynamic environments (see the complexity results established in [64] and [41]), it seems unlikely that a hard real-time constraint could ever be met in realistic situations. *Partial Motion Planning* (PMP) is our own answer to the problem at hand. PMP operates according to the following principle:

Compute the best *partial motion* towards the goal given the planning 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. The PMP cycle is depicted in Fig. 15. The iterative nature of PMP 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 reactive approaches, PMP faces two issues, namely the convergence and the safety issues:

Convergence. What guarantee do we have that the goal will ever be reached?

Safety. What guarantee do we have that the robotic system will never found itself in a dangerous situations?

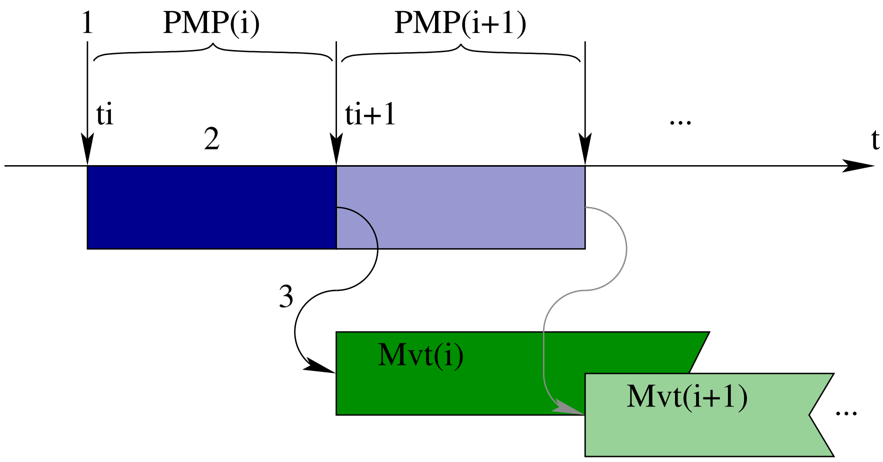


Figure 15. The Partial Motion Planning cycle.

As for the convergence issue, the unrealistic convergence conditions established in [59] leave little hope (it is hardly surprising if the system is placed in an environment with no a priori information about the moving obstacles). To address the safety issue, two different solutions are explored: 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).

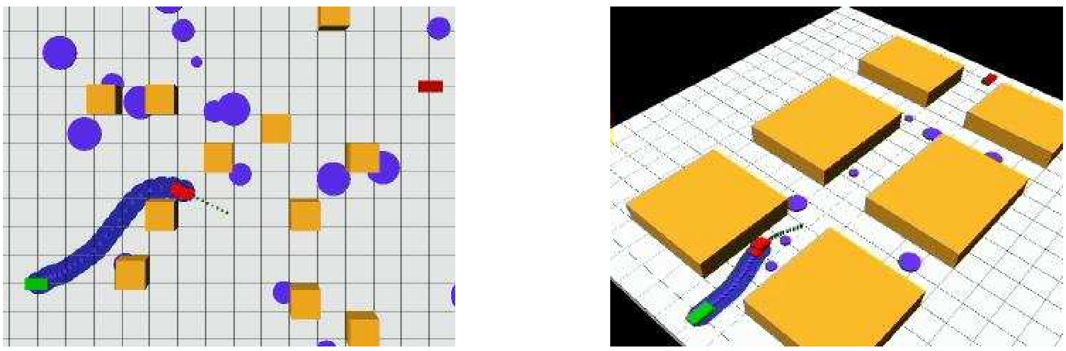


Figure 16. PMP for a car-like vehicle in different situations

In 2004, a complete prototype of PMP using the Inevitable Collision States has been implemented and tested in simulation for a car-like vehicle (Fig. 16). This work has yielded a paper that has been published at the IEEE-RSJ Int. Conf. on Intelligent Robots and Systems [21]. In 2005, the focus has been on the integration of the PMP module within the software architecture of a Cycab experimental vehicle (coupling with the control level of the vehicle). Preliminary experiments were carried out live during the Nancycab event that took place in Nancy on June 17-18, 2005.

6.3.5. Inevitable Collision States

Participants: Thierry Fraichard, Stéphane Petti.

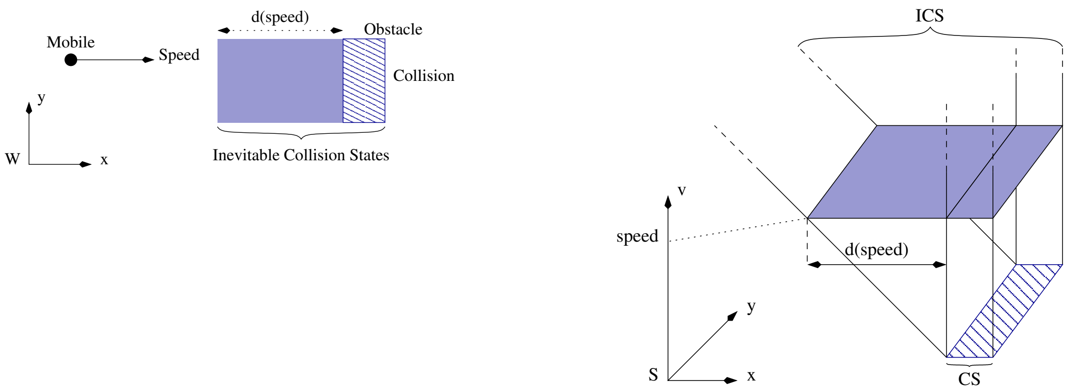


Figure 17. Collision states (CS) versus Inevitable Collision States (ICS): representation in the workspace $\mathcal{W}$ of the system $\mathcal{A}$ (on the left) and in its state space $\mathcal{S}$ (to the right).

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) [37]. 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 and 2004 were dedicated to further the exploration of the ICS concept by demonstrating a number of properties are fundamental for their characterisation [48]. 2005 was mostly spent studying the use of the ICS concept to guarantee safety within the PMP 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 PMP, it is presented in a paper that has been published at the IEEE-RSJ Int. Conf. on Intelligent Robots and Systems [21].

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 [66], 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 [55]. 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. 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 which lead to 2 publications [71], [70] (*cf* section 6.1.4). In 2005, A new ph-D student (C. Fulgenzi) will keep on working on NLVO combined with occupancy grids.

6.4. Probabilistic Inference and Decision

6.4.1. Bayesian Robot Programming

6.4.1.1. Bayesian Approach to Action Selection and Attention Focusing

Participants: Carla Koike, Albino Pereira, Pierre Bessière.

Autonomous sensory-motor systems, situated in dynamic environments, must continuously answer the ultimate question: how to control motor commands knowing sensory inputs?

Solving this question is a very complex problem, because a huge flow of information must be treated under several restrictions: real-time constraints, bounded memory space, and limited processing power. One additional and major challenge is to deal with incomplete and imprecise information, usually occurring in dynamic environments.

Since last year, we address the problem of controlling autonomous sensory-motor systems, and in 2005 we formalize the programming framework using a Bayes Filter that includes action and attention selection mechanisms [13].

Partial independence between different domains of interest is exploited to reduce further the dimensionality of the problem while preserving coherence in system decisions. A behaviour selection mechanism expresses the global behaviour as composed of a repertoire of simple and independent motor patterns; Attention focusing, guided by behaviour intention, reduces preprocessing time of incoming perception data.

The proposed Bayes Filter was implemented on a mobile robot [32]. Experiment includes interaction with subjects, as shown in Figure 18.

Figure 18. BIBA robot facing predator and trainer, at left. At right, the robot detects prey.

6.4.2. Bayesian Learning

Participants: Ronan Le Hy, Pierre Dangauthier, Pierre Bessière, Anne Spalanzani.

In order to deal with the uncertainty and the incompleteness of the world, we use Bayesian methods to program our robots. A Bayesian program is a probabilistic representation of the relations between sensors and actuators in order to perform a specified task.

In this framework, a Bayesian programmer starts to describe the task by specifying **preliminary knowledge** to the robot. Then the robot processes Bayesian inference in order to take a decision regarding its inputs.

Establishing preliminary knowledge can be divided into three parts:

- Define relevant variables for the problem;
- Possibly assume conditional independencies between them;
- Choose prior distributions on those variables.

Usually this preliminary knowledge comes from the human programmer, but a really autonomous robot should be able to discover that kind of information. This is why we focus on applying machine learning methods in order to automate the design of bayesian programs.

6.4.2.1. Learning Preliminary knowledge

This year, we finalized an attempt to automate the discovery of the “relevant variables” part of a new program. This has been achieved under the supervision of another Bayesian Program, and has been published in ICRA’05[17]. An adaptation of this method, called “Feature Selection For Self-Supervised Learning” has been presented in an AAAI worshop on Developmental Robotics [29].

On top of that, we developed a genetic algorithm framework for learning the third kind of prior knowledge (“parametrical forms”) in the context of a simple visual tracking task.

We now focus on learning the last part of the prior knowledge, *ie*the conditional (in)dependencies beetween variables. This is strongly related to the field of structure learning of bayesian networks. Our approach differs from usual methods by the use of information theoric heuristics. The notions of entropy and mutual information are employed to mesure the information gained during the learning process.

6.4.2.2. Bayesian Behaviors for Video Game Characters

Bayesian programming techniques used in robotics can be applied to synthetic characters such as those in video games. Games actually provide for rich virtual worlds in need of intelligent autonomous creatures. Both game play and development methodologies can benefit from Bayesian representations of automata-like behaviour models, and the learning techniques that they can naturally host.

We have pursued work on developing Bayesian programs for behaviour selection and execution for video game characters. Previous results (see [58] 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 video game characters. We have focused on learning behaviours by demonstration, which includes developing methods to identify human playing behaviours [57]. Our current work amounts to synthesizing a complete programming methodology for complex behaviours, based on learnable hierarchical Bayesian models.

6.4.3. Models and Tools for Bayesian Inference

Participants: Juan-Manuel Ahuactzin Larios, Pierre Bessière, Emmanuel Mazer, Manuel Yguel, Ronan Le Hy, Aurelien Chenet.

ProBT is a C++ library for developing efficient Bayesian software. This library has two main components: (i) a friendly Application Program Interface (API) for building Bayesian models and (ii) a high-performance Bayesian inference and learning engine allowing execution of the probability calculus in exact or approximate ways. This paper is not intended to describe ProBT. It will only focus on its underlying inference algorithms.

The aim of ProBT is to provide a programming tool that facilitates the creation of Bayesian models and their reusability. Its main idea is to use “probability expressions” as basic bricks to build more complex probabilistic models. The numerical evaluation of these expressions is accomplished just-in-time: computation is done when numerical representations of the corresponding target distributions are required. This property allows designing advanced features such as submodel reuse and distributed inference. Therefore, constructing symbolic representations of expressions is a central issue in ProBT.

6.4.3.1. Approximate inference in ProBT

6.4.3.2. A ProBT interface for fast Bayesian modeling

In order to facilitate the usage of ProBT, either by novice or expert users, we started the development of a web based ProBT interface. This tool written in PHP is intended to translate a Bayesian model into its equivalent in ProBT. Thanks to this interface users will be able to quickly and easily run, test and modify their models. All this without knowing C++ nor a single class of the ProBT API.

This facility allows us to concentrate our attention on the task of modeling rather than in the coding work. Especially when the user is not familiar with the Bayesian programming paradigm.

For an advanced user this tool allows the recovering of the generated C++ code so that it can be integrated in more elaborated programs.

At this date we have implemented the interface that allows to write a Bayesian program: specify the variables, the joint distribution, the parametric forms and the question. We are working in the development of more elaborated interfaces according to the class of problem: Bayesian filter, sensor fusion, Classification, etc.

6.4.3.3. Improvements in marginalization algorithms

One of the main goals of Bayesian computation in ProBT is to construct a symbolic evaluation tree by finding a corresponding sum/product ordering that takes into account the computational constraints of the application (computation time and/or memory size). This year we worked on the improvement of these algorithms.

Given a target joint distribution query, exact inference in ProBT consists of:

- constructing an “exact expression” (evaluation tree) that organizes the sum/product operations sequence
- using this evaluation tree to compute or update the corresponding probability table.

The algorithm we implemented and improved to construct such an evaluation tree is called the “Successive Restrictions Algorithm”. It is a goal-oriented algorithm that tries to find a marginalization (elimination) ordering for an arbitrary target joint distribution. This algorithm has been developed in collaboration with the University of Marne-La-Valle and the Probayes company.

Given a Bayesian network relative to a set of random variables $\mathbf{X}_U = \{X_1, X_2, ..., X_n\}$ taking values in finite sets $\{\mathbb{S}_1, \mathbb{S}_2, ..., \mathbb{S}_n\}$, we are interested in computing the joint probability distribution (called the target) of a subset of random variables $\mathbf{X}_L \subset \mathbf{X}_U$, conditionally to another subset (possibly empty) of random variables $\mathbf{X}_R \subset \mathbf{X}_U$, where $(\mathbf{X}_L \cap \mathbf{X}_R) = \varnothing$. This target distribution is denoted $P(\mathbf{X}_L \mid \mathbf{X}_R)$.

According to Bayes's theorem, we have:

$$P(\mathbf{X}_L \mid \mathbf{X}_R) = \frac{P(\mathbf{X}_L \cup \mathbf{X}_R)}{P(\mathbf{X}_R)} = \frac{P(\mathbf{X}_L \cup \mathbf{X}_R)}{\sum_{\mathbf{X}_L} P(\mathbf{X}_L \cup \mathbf{X}_R)}. \tag{1}$$

Therefore, to compute this conditional probability we must calculate the probability distribution of $(\mathbf{X}_L \cup \mathbf{X}_R)$, which requires marginalizing out a set of variables $\mathbf{X}_{\overline{U}} = (\mathbf{X}_U - (\mathbf{X}_L \cup \mathbf{X}_R))$, from the joint distribution $P(\mathbf{X}_U)$ corresponding to the BN. The main idea in our algorithm is to find a way to manage the succession of summations on all random variables $X_i \in \mathbf{X}_{\overline{U}}$.

The objective of finding a marginalization (elimination) ordering for an arbitrary target joint distribution is shared by other variable elimination algorithms. However, the SRA algorithm has two additional objectives:

1. The construction of a symbolic probability expression (evaluation tree) representing the elimination ordering regardless of the numerical values to be used in the effective numerical evaluation.
2. All intermediate computations produce probability distributions instead of simple potentials. In other words, each node of the evaluation tree represents a probability distribution on a subset of variables. This property is very important in ProBT because each node of this tree (expression) may be replaced at runtime by another distribution.

6.4.3.4. 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] and CyberCars2 (under signing with EC)
  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.
- Profusion [February 2004-February 2008]
  European project, PreVENT Programme (Preventive and Active Safety Applications) Profusion, “Project for Robust and Optimized Perception by Sensor Data Fusion”
  The second phase of ProFusion started in April 2005. The goal of this second phase is to develop new concepts, methods and theories for sensor data fusion for Automotive Industry. These solutions will permit to perceive the environment surrounding a car and automatically build a model of this environment. This model will be interpreted it in order to assist the car driver. The resulting prototypes will be tested and validated on European car demonstrators. The specification and design of the system for sensor data fusion is still in development until the beginning of 2006. In 2006, the development of algorithms and methods will start, and the integration of the resulting prototypes on european car manufacturers demonstrators is planned for 2007. Our group plans to integrate its prototype on a Volvo truck and a Mercedes-DaimlerChrysler car.
  The Profusion phase2 consortium is constitued of 10 european car manufacturers, suppliers and research institutes: (BMW, CRF, DaimlerChrysler, Delphi, Forwiss, ICCS, INRIA, Sagem, TUC, Volvo).

- Puvame [October 2003-April 2006]
  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) and Imara project (Inria Rocquencourt), Ecole des Mines de Paris (EMP), INRETS, Intempora, Probayes, Robosoft, Connex.
  A first prototype has been developped and tested on our Parkview platform. This prototype validates perception solutions to intersection safety avoiding collisions between vulnerable road users and bus. In 2005, this prototype has been improved on several points: (i) Integration of techniques to improve the prediction of the trajectory of pedestrians crossing an intersection. These techniques are based on the work done in our group on online intentional motion learning and prediction. (ii) Use of two cameras to observe the intersection and fusion of informations to improve the robustness of the perception.
- 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.
- Previous Contracts European project IST 1999-12224 Carsense [2000-2003] with INRIA, INRETS/LIVIC, Renault, BMW, Lucas Varitu, Thomson Detexys, Ibeo. National project ARCOS [2003-2004] with ENSMP, INRETS/LIVIC, SUPELEC, UTC. Industrial project with Kelkoo [2003-2004] and Probayes Start-up. RNTL Collaboration project AMIB-E [2002-2004] with MGE UPS SYSTEMS and TEAMLOG. PRIAMM National project Visteo [2000-2004] with GETRIS images and INRIA.

8. Other Grants and Activities

8.1. Other funding, public, European and Regional

- 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*[4] 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).

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

- ICT-Asia “FACT”[October 2005- Decembre 2007]
  The Fact project is a joint research project in the scope of the ICT-Asia programme founded by the French Ministry of foreign affairs, the CNRS and INRIA. It aims at conducting common research activities in the area of Intelligent Transportation Systems (ITS). The main objective is to develop new technologies related to the concept of “Cybercar”. The project involves the following research teams : e-Motion project at INRIA Rhône-Alpes (leader), Imara project at INRIA Rocquencourt, LASMEA Laboratory at Clermont-Ferrand, SungKyunKwan University (Korea), Shangai Giao Tong University (China), Nanyong Technological University (Singapore) and Tokyo University (Japan).

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).

8.2.1.3. Collaboration with Korea

In the scope of the France-Korea Safemove project, *e-Motion* has a collaboration with the SungKyunKwan University at Suwon (Korea).

8.2.1.4. Collaboration with Japan, Singapore, Korea, China

see the description of the ICT-ASIA “Fact” project above.

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 Rhône-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.

8.2.2.2. 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 (e.g. Remis Balaniuk, Cesar Mendoza). This collaboration has been stopped this year, because the e-Motion project stopped to work on this topic.

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 since 2000.

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. Informal exchanges are still going on on this topic.

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* participate 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 : National programme in Robotics ROBEA, and inter-ministerial PREDIT group 9 on new technologies for transport.
- Th. Fraichard was a member of the organization committes of the Second Korea-France Symposium on Dependable Robotic Navigation, Seoul (KR), October 2005.
- 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: Guanajuato (MX) Antipolis (FR) [July 2005]. *Teacher: Th. Fraichard.*
- Lecture “Robotic”s, Summer school "Automatic Control for Production Systems", Grenoble [June 2005]. *Teacher: Th. Fraichard.*
- Lecture “Advanced motion planning”, Post-Master Course, Mathematics Informatics INPG-UJF Doctoral School, Grenoble. *Teacher: Th. Fraichard.*
- Lecture “Outils probabilistes et statistiques pour l’Informatique”: (every year): Licence d’Informatique de l’Université Joseph Fourier 3ème année, Grenoble, (FR). *Teacher: O. Aycard*.
- Lecture “Inférence et apprentissage bayesien": (every year): Master d’Informatique de l’Université Joseph Fourier 1ère année, Grenoble, (FR). *Teacher: O. Aycard*.
- Lecture “Inférence et apprentissage bayesien": (every year): Ecole Polytechnique Universitaire de Grenoble, Filière Technologies de l’Information pour la Santé 3ème année, Grenoble, (FR). *Teacher: O. Aycard*.
- Lecture “Raisonnement bayesien”: (every year): Master 2ème année “Imagerie, Vision, Robotique” de l’INPG, Grenoble, (FR). *Teachers: P. Bessière and O. Aycard*.
- Lecture “Bayesian techniques for perception”: France-Mexico Summer school on “Image and Robotics” (every year). *Teachers: O. Aycard*.
- Tutorial on “Safe Navigation in Dynamic and Open Environments”: Singapore, November 2005. *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.*
- Lecture on Bayesian Approach to Banking Operational Risk, Paris, December 2004 and March 2005. *Teacher: P. Bessière.*
- Lecture on Bayesian (Robots) Programming, BIBA winter school 2005, London, January 2005. *Teacher: P. Bessière.*
- Lecture on Bayesian Analysis (perception, probability, geometry), Math and Brain summer school, Paris, July 2005. *Teacher: P. Bessière.*
- PostGrade lecture at EPFL on Bayesian Inference and Learning. 2005. *Teacher: P. Bessière.*

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 2005 summer school on “Image and Robotics” at the University of Guanajuato, Mexico (July 2005).
- C. Laugier participates 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.
- O. Aycard is member of the programme committees of the CIRAS’2005 conference.
- A. Spalanzani is part of the editorial commitee of the *In Cognito* cognitive sciences journal.
- Th. Fraichard gave an invited talk entitled *Safe motion planning in dynamic environments* at the Motion Planning in Virtual Environments workshop, Toulouse (FR), *January 2005*.
- P. Bessière is a member of the editorial committees of the following conferences :
  - Conference ESANN (European Symposium on Artificial Neural Networks)
  - Conference RFIA (Reconnaissance des Formes et Intelligence Artificielle)
  - Conference IEEE/ICRA (International Conference on Robotics and Automation)
  - Conference IEE/IROS (International Conference on Intelligent Robots and Systems)
  - Conference EA (International Conference on Artificial Evolution)
- P. Bessière reviews regularly in the IEEE Transactions on Evolutionary Computation and Autonomous Robots journals.

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