INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team e-Motion

Geometry and Probability for Motion and Action

Rhône-Alpes

THEME 3B

Activity Report

2003

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2. Overall Objectives

2.1. Overall Objectives

The project-team *eMotion*, is common between Inria, CNRS, the Institut National Polytechnique of Grenoble, and the university Joseph Fourier of Grenoble; it is localised at Inria Rhône-Alpes, and also belongs to the laboratory Gravir[5] of the Imag federation.

The project-team *eMotion* aims at developing algorithmic models and methods allowing to build *"artificial systems"* equipped with capacities of perception, decision, and action sufficiently advanced and robust to allow them 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 sensors technology, and on miniaturised mechatronic systems, make the required technological breakthroughs potentially possible (including from the scalability point of view).

In order to try to reach this objective, we propose to combine the respective advantages of the *computational geometry*, of the *theory of probabilities*, and in certain cases of the *biological inspiration* (by working in cooperation with some neurophysiologists). This approach leads us to study, under these different points of view, three strongly correlated fundamental subjects:

- *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).
- *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.

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- *Probabilistic inference for decision*. The problem to solve is to be able to correctly reason about both the current knowledge of the system and its associated uncertainties.

The main applications aimed by these research axes are those aiming at introducing advanced and secured robotised systems into our "living space", in order to increase the safety of people and the comfort of use of new technologies. We can find such characteristics in applications such as future cars and transportation systems, or service and intervention robotics (e.g. domestic tasks, civilian or military security, entertainment). We can also expect some other spin-offs of this research in various applications domains such as the interaction with autonomous agents in a virtual world, the modelling of biological sensory-motor systems, or the diagnosis for the maintenance of large industrial plants or for financial applications (application domains currently covered by our start-up *Probayes*).

3. Scientific Foundations

3.1. Background

Long time source of inspiration and field of experimentation for research in Artificial Intelligence, *Robotics still runs into the problems of scalability and of the real integration of robotised systems in our everyday life, despite significant progress these last years*.

The reason for this stems primarily from the fact that models and technologies developed in the past have reached their limit of appropriateness so as to cross the complexity gap introduced by the physical environments in which we live (natural or conceived for humans). Indeed, such environments are richer in information, introduce significant dynamicity, are unpredictable by nature and imply complex interactions with humans: they demand decision-making processes and actions on the basis of incomplete information. In the past decades, researchers in the fields of Robotics and of Artificial Intelligence have tried to solve some of these problems by using various approaches that quickly reached their limits. This is in particular the case of logic in the Seventies which showed to be ineffective to solve motion problems in the real world, and of geometrical methods in years 80-90, even completed by the introduction of random search techniques to handle the intrinsic algorithmic complexity of those problems which have shown their inability to master the computation times and a poor general effectiveness regarding concrete problems (even if some industrial applications start to use these principles). Moreover, with respect to the complex and poorly reactive traditional decisional schemes, reactive architectures at the beginning of the Nineties failed to meet the expectations as soon as the applications left the academic field.

Indeed, all the previous approaches have brought some partial contributions to the solution of the general problem; however, they generally allow robots to acquire the necessary autonomy properties only in artificial environments carefully fixed up for them and generally ill-adapted for human. The main cause of these limitations, or even failures, is owing to the fact that those approaches did not explicitly take into account the intrinsic "incompleteness" of models issued from classical tools, stressing the necessity *to look for means to formalise this "incompleteness" and to better model the intricate "complexity" of the real world*. The ambition of the project-team *eMotion* is to bring solutions to these difficult problems, still very little addressed by our scientific community.

3.2. Problems Addressed

The general objective presented in section 1, leads us to tackle at once the underlying problems of *complexity* and of *incompleteness*. This approach is necessary for trying to carry out 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 behaviours of the potential obstacles).

• *Increased robustness of the automatic navigation processes (perception and control).* 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 mechanisms of decision-making (see next section).

• *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. For that purpose, we will combine incremental map reconstruction techniques and our new concept of *Bayesian Programming* (see next section).

3.3. Research Axes and Approaches

Our approach for solving the previous problems consists in combining the respective advantages of Computational Geometry, the theory of probabilities, and in certain cases, biological inspiration (to that end, we are working with neurophysiologists). This leads us to study three fundamental topics that are strongly correlated: (1) multimodal modelling of space and motion, (2) planning of motions in the physical world, and (3) probabilistic inference for decision.

- *Multimodal and incremental modelling of space and motion:* our goal is to use preliminary knowledge and a continuous flow of perceptive data, to incrementally build several types of models with complementary functional specialisations (this approach is supported by by theories in Neurophysiology such as the theory on the memorisation of space and motion developed at the Collège de France by Alain Berthoz [46]). The intrinsic nature of the problem (world dynamicity, environment complexity, hazards, etc.) leads us to make use of an incremental approach involving techniques to predict the motions of the perceived obstacles, and techniques for combining sensing data and executed actions. Both geometric methods (*eg* SLAM) and probabilistic techniques based on machine learning (*eg* for motion prediction, for building Bayesian sensory-motor maps) will be used.
- *Motion planning for the physical world:* the main problem is to take into account simultaneously various constraints of the physical world such as non-collision, system dynamics, environment dynamicity, and limited response time, while mastering the related algorithmic complexity. These characteristics lead us to develop techniques for reasoning on appropriate representations of the space-time, e.g. space of instantaneous safe speeds or iterative planning under strong temporal constraints. Moreover, the real implementation of these techniques in physical robots leads us to take into account their mechanical constraints (kinematics and dynamics), where arise control problems that need to be tackled in an algorithmically efficient way. In order to cope with these problems, we propose to combine analytical and probabilistic models searching for a safe and robust evolution of the robot by means of the effective fusion of control techniques, issued from the theory of control, with reactive behaviours coming from probabilistic inference methods.
- *Probabilistic inference for decision:* the problem to solve is to be able to correctly reason about both the current knowledge of the system and its associated uncertainties. The theory of probability is basically a formal framework which seems to be well adapted for such a type of reasoning. For coping with this problem, we propose to make use of the new principle of "Bayesian programming" developed by our research team. This approach potentially provides formal constructions and computational tools to carry out machine learning and reasoning based on probabilistic inference.

4. Application Domains

4.1. Application Domains

As previously mentioned, the main applications aimed by the previous research axes are those aiming at introducing advanced and secured robotised systems into our “living space”. We can find such characteristics in applications such as future cars and transportation systems, or service and intervention robotics (e.g. domestic tasks, civilian or military security, entertainment). We can also expect some other spin-offs of this research in various applications domains far away from robotics applications.

- *Future cars and transportation systems.* This application sector 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 *assistance mechanisms* aimed at improving comfort and safety of the cars users, and in *automatic driving functions* allowing fully automatic displacements of private or public vehicles in particular driving situations (e.g. ACC, emergency braking) and/or in some equipped areas (e.g. automated car parks or captive fleets in downtown centres).
- *Service and intervention robotics.* This application sector 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 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* commercialising products based on Bayesian programming).

5. Software

5.1. ColDetect

Participants: Christian Laugier, Romain Rodriguez, Kenneth Sundaraj.

We have released a library for collision detection called **ColDetect** based on our previously developed algorithms [63][62] and other algorithms that we have developed this year [41]. ColDetect is a library for *collision detection, exact distance computation, and contact localisation of three-dimensional polygonal objects. These objects can be concave or convex, rigid or deformable*. It is numerically robust - 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. It provides a very simple API. This library can be downloaded from http://www.inrialpes.fr/sharp/coldetection.

5.2. ProBT

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

ProBT (formerly known as OPL) 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.

To date, ProBT is the main Bayesian programming tool of the eMotion project, several theses use this library as part of their main test bed system. Furthermore, ProBT is used in a variety of external projects both in the academic and industrial field.

5.3. 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 year. 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. These tools were used in a collaboration with the RIA team (LAAS, Toulouse), and are now widely used in our team to prepare real CyCab experimentations.

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, Jean Lorieux, Christopher Tay Meng Keat.

Figure 1. Detected cars with Hough transform

Simultaneous localization and mapping is a well known problem in the robotic community as long as static environment are concerned. Having demonstrated last year our ability to perform localization and mapping in such an environment[9], we were able this year to use these abilities in real world experimentation on trajectory tracking and obstacle avoidance which were reported in important conferences and journal of the field [7], [28]

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

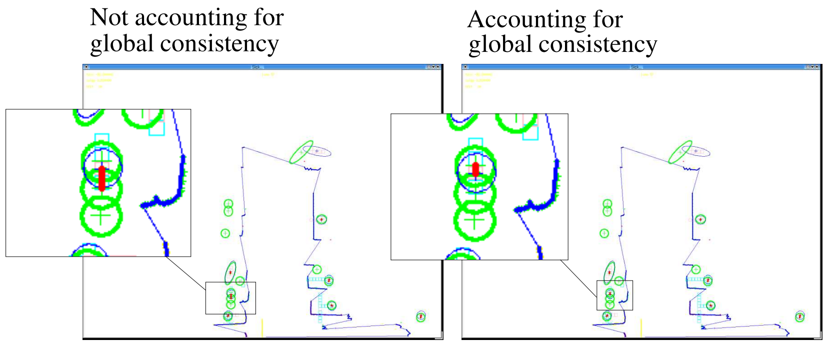


Figure 1: Extracting hypothesised parked cars with the global consistency branch and bound method.

Figure 2. Extracting hypothesised parked cars with the global consistency branch and bound method.

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 parked or when a parked car left; thirdly, using static cars has landmarks, we can refine our position estimation in the car park and estimate other cars' movement.

First part of this work, i.e. hypothesized car extraction was conducted till june by a DEA student (J.Lorieux,[38]) and a new DEA student (C.Tay Meng Keat) is continuing on the second objective. Figure 2 shows hypothesized cars(rectangles) extracted from a laser scan Figure 1 shows how hypothesized cars are associated between two laser scans, putting the stress on the need for robust data association techniques : correct data association is achieved using whole map uncertainty model(right figure) instead of individual uncertainty model (left figure).

6.1.2. Moving Objects' Future Motion Prediction

Participants: Thierry Fraichard, Frédéric Hélin, Alejandro Dizan Vasquez Gomea.

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 long-term motion prediction for moving objects. Assuming a structured environment and following the observation that moving objects usually follow typical motion patterns that can be observed consistently, we have settled for a technique aiming at learning these typical motion patterns and using them for motion prediction. The approach we have designed operates in two stages:

- *Learning stage:* observe the moving objects in the environment in order to determine the typical motion patterns.
- *Prediction stage:* use the typical motion patterns learnt to predict the future motion of a given object.

Our approach is cluster-based: sets of partially or wholly similar observed trajectories are clustered together. A representative trajectory for each cluster is computed and used for motion prediction.

We have proposed a novel cluster-based technique that learns the typical motion patterns using pairwise clustering. We introduce a dissimilarity metric that allows the use of any clustering algorithm which can operate over a dissimilarity matrix. As a result, we obtain a number of clusters corresponding to the different typical motion patterns. Then, we calculate the mean value for every cluster, which we further use to predict motion for a partially observed trajectory.

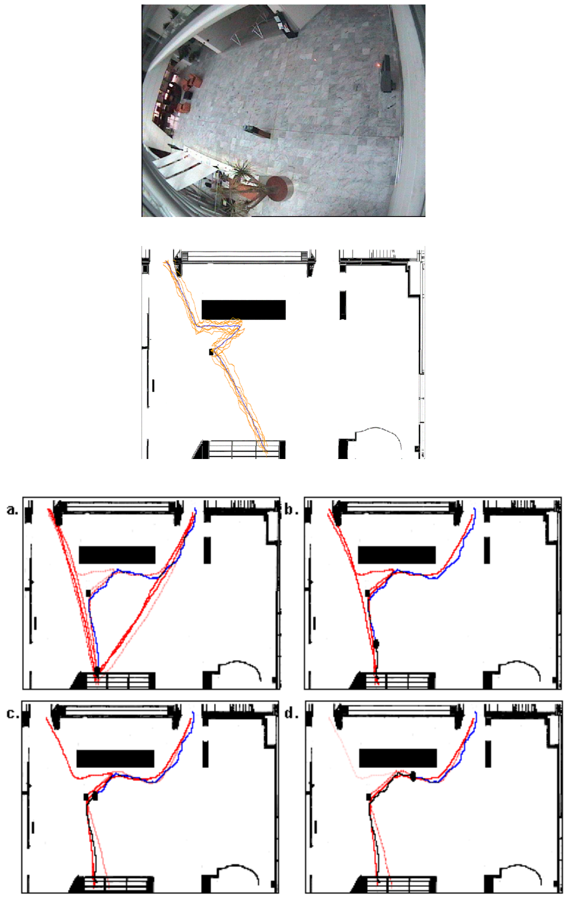


Figure 3. Moving obstacles prediction: (top-left) the environment (Inria Rhône-Alpes's main lobby), (top-right) a cluster example, (bottom) an on-line prediction: in blue, the moving object's future motion, in red, the predictions made (the redder, the more likely).

We have implemented our approach using both simulated and real data coming from a vision system (Fig. 3). The results show that the technique is general, produces long-term predictions and is fast enough for its use in real time applications [43]. To further evaluate our approach, we have compared it with an alternative approach based upon Expectation-Maximisation [45]: it fared better than Expectation-Maximisation. In the future, it is planned to test the approach with real observations obtained from the ParkView testbed currently being installed on the Inria Rhône-Alpes's parking lot [37].

6.1.3. Dynamic Scenes Interpretation by Bayesian Data Fusion

Participants: Pierre Bessière, Christophe Coué, Thierry Fraichard, 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 [47] 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. We called the corresponding model the *bayesian occupancy filter (BOF)* [1]. This model is inspired by *occupancy grids* which have been extensively used for mapping and localisation in static environments.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 [12].

6.1.4. Bayesian Maps

Participants: Julien Diard, Pierre Bessière.

This work is concerned with the modeling of the environment a mobile robot has to face in a navigation task. This is a crucial problem, that has received a lot of attention in different communities. On the one hand, the most successful practical achievements have been obtained using the probabilistic calculus ([64][65][66][14]), thanks to its sound theoretical basis. On the other hand, biomimetic models of navigation ([67][56][57]), while not as applied as the probabilistic models, are centered on the notion of hierarchical and modular models, which gives flexibility and the possibility of incremental development. A theoretical comparison of these approaches shows their complementarity ([50]). We have proposed a possible marriage between probabilistic and biomimetic models: the *Bayesian Map* formalism ([2]), which is based on the bayesian framework, and defines operators for combining probabilistic models of space: the Superposition operator ([52][15]), which allows for merging models built from different sensory modalities, and the Abstraction operator ([51][16]), which allows for building hierarchies of sensorimotor models.

6.1.5. Physical Models and 3D Interaction

Participants: César Mendoza Serrano, Kenneth Sundaraj, Christian Laugier, Miriam Amavizca, Romain Rodriguez.

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

- Physical Models for Soft Tissue Simulation
- Collision Detection for Medical Simulators
- Computer Aided Surgery

6.1.5.1. Physical Models for Soft Tissue Simulation.

We have developed a new physical model for soft tissue simulation. This model is called the Volume Distribution Method (VDM) [29]. This new 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) [49]. 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.

6.1.5.2. Collision Detection and 3D Interaction.

We have worked on two new algorithms for collision detection this year [41]; an algorithm for distance computation between concave objects and an algorithm for fast collision detection of deformable objects. These algorithms have been intended mainly to be used in medical simulators where concave and deformable objects form the major part of the simulated environment. Our main contribution is the use of a single underlining data structure for interference queries. Axis-aligned bounding boxes has been chosen because this type of hierarchy can be updated in a fast and efficient manner. We believe that this choice is optimal and memory efficient.

This year, we have also developed and implemented the first algorithm for interactive cutting of soft tissue [25][5][24]. Within this context, we have investigated some representative models that describe the physical behavior of biological tissues. We have studied their advantages and limitations and we have chosen to use an *explicit formulation of finite element models* for authorizing interactive topological changines (cutting in particular) of the simulated biological tissues.

6.1.5.3. Computer Aided Surgery.

Within this context, we have continued the development of the following prototype medical simulators; Echographic Thigh Exam (ETE), Arthroscopy Knee Reconstruction (AKR) and Total Hip Replacement (THR). In the ETE simulator, based on assumption that the thigh exhibits volume conservation, we examined the feasibility of using the VDM model to represent the human thigh. In the AKR simulator [29], we have developed a prototype, in collaboration with Aesculap-BBraun, to assist the surgeon to manage anterior cruciate ligament (ACL) reconstruction. We contributed to the proposition of a CT-Free system that solves both these constraints in real-time and intra-operatively. The THR simulator aims at solving the problem of effective hip prosthesis positioning. A defective placement of the prosthesis can lead to various complications; for instance the luxation of the prosthesis or reduction in the mobility of the hip. In this project, we aim to optimize the effective placement of the prosthesis.

6.2. Motion planning for the physical world

6.2.1. Motion Planning and Execution for the Cycab

Participants: Jorge Hermosillo, Sepanta Sekhavat, Christian Laugier.

The Cycab robot is a special class of four-wheel robot with double steering axles. We call it *bi-steerable car* since it is capable of steering its rear wheels in function of the front steering angle. The differential equations describing the control system set new problems of motion planning and control in mobile robotics (*eg*see [58]). The methodology employed to solve these problems is framed within the theory of *differential flatness* [53], where the objective is to find state and control transformations, putting the system in a convenient form for control design purposes. Our research has shown first that the Cycab is *flat* [60]. Notwithstanding, the major difficulty, and open problem in the general case, is to find transformations yielding a flat output of the system. Hence we first establish theoretical results leading to a necessary condition on the coordinates transformations yielding a linearizing output for the Cycab. We make this result effective by proposing the first complete motion planner for this kind of mechanical structure, and a simple control scheme to solve the trajectory tracking problem [21]. Experimental results validate these theoretical issues [19].

6.2.2. Safe and Autonomous Navigation of the CyCab Robot among Pedestrians

Participants: Cédric Pradalier, Jorge Hermosillo, Christophe Braillon, Carla Koike, Pierre Bessiere, 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

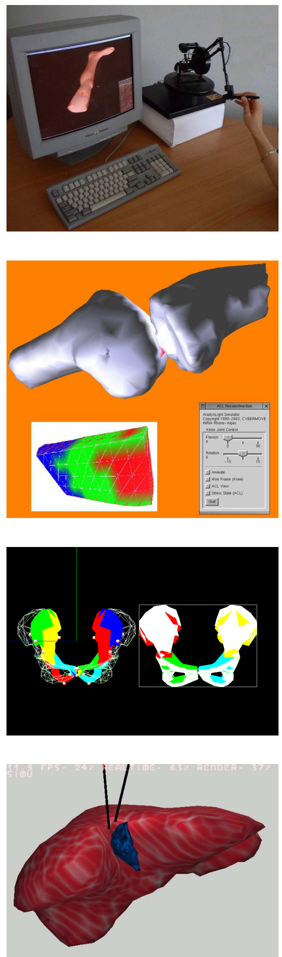


Figure 4. The developed medical simulators; Echographic Thigh Exam, Arthroscopy Knee Reconstruction, Total Hip Replacement and Interactive 3D Cutting.

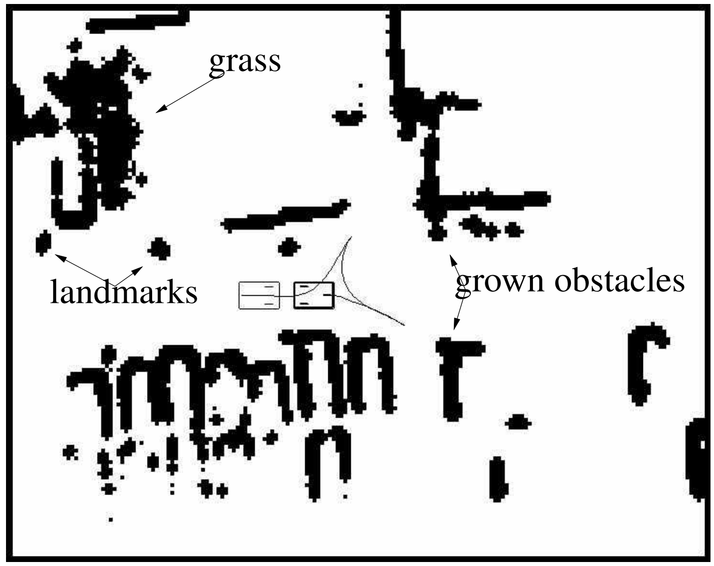


Figure 5. Simulated path computed by the motion planner in a work-station using a real obstacle map generated by the previously described map-building stage. The obstacles are grown as well as the robot before computing the path.

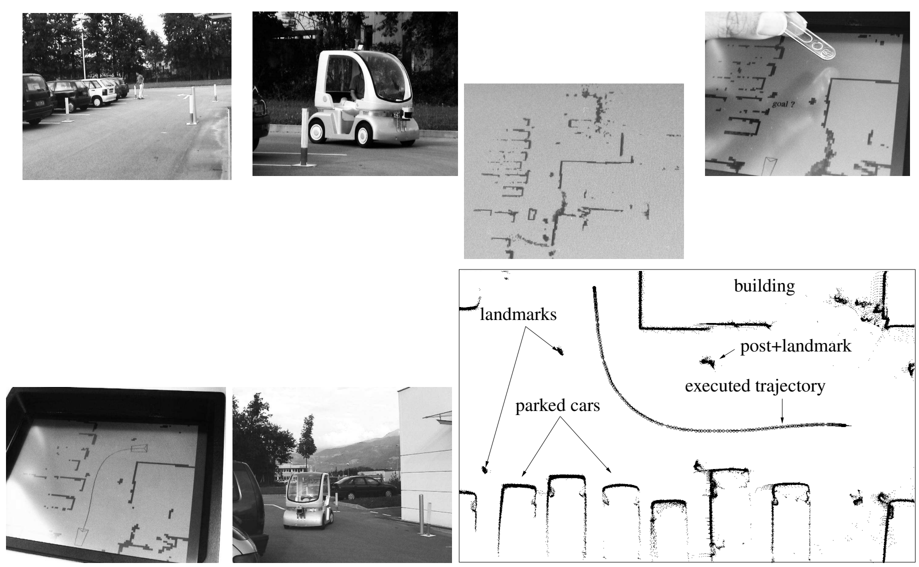


Figure 6. An experimental setting showing from left top to bottom right: The arbitrary placing of the landmarks; the manual driving phase for landmark and obstacle map-building; the obstacle map generated together with the current position of the robot as seen on the LCD display; the capture of the goal position given by the user by means of the touch-screen; the reference path found by the motion planner; the execution of the maneuver using a linear control law; and the executed trajectory recovered after the experiment.

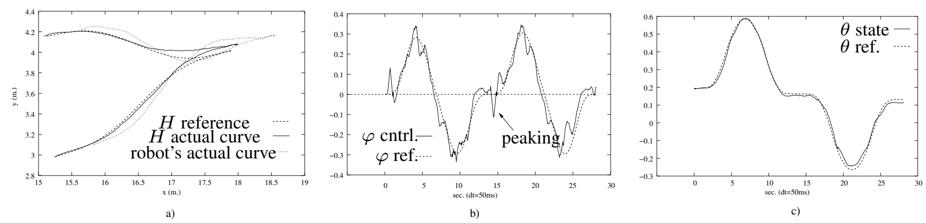


Figure 7. Parking maneuver experimental setting: a) Reference curve for point H and actual curves for this point and for the robot (i.e. point F); b) Reference and actual curves of the steering angle control φ (the control system is sensible at cusp points inducing "peaks"); c) Reference and actual orientation of the robot θ.

CyCab flatness property ([21]) 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. Part of this work has been published in IARP WorkShop on Service And Personal Robotics (SAPR) ([28]). An extension was submitted to the ICRA 2004 conference ,and complete work has been submitted to the Robotic And Autonomous System journal.

Figure 8. An experimental setting showing the execution of a pre-planned trajectory among pedestrians and unaccounted for vehicles.

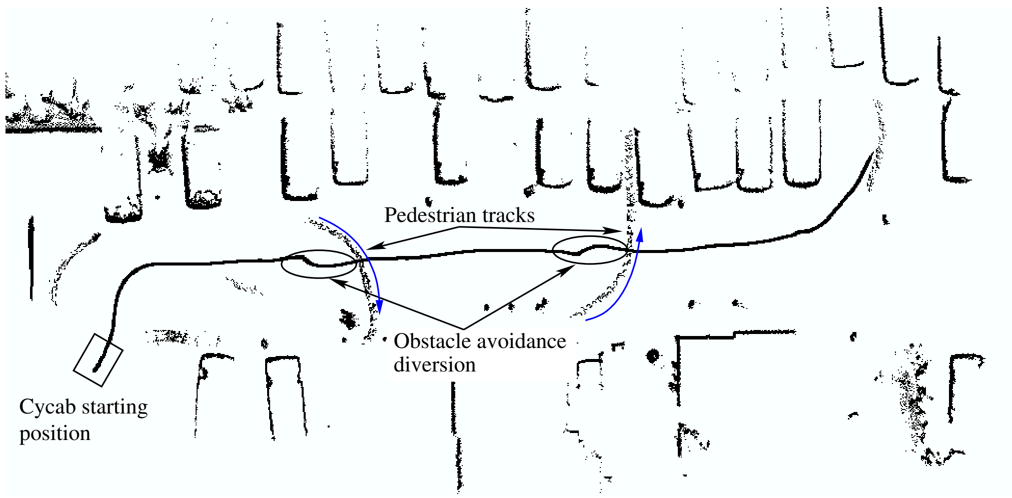


Figure 9. Executed trajectory among static obstacles and moving pedestrians.

6.2.3. Iterative Trajectory Planning

Participants: Thierry Fraichard, Frédéric Large, Stéphane Petti, Christian Laugier.

To navigate or plan motions for a robotic system placed in an environment with moving obstacles, reasoning about the future behaviour of the moving obstacles is required. In most cases, this future behaviour is unknown and one has to resort to predictions. In this context, motion planning faces a double constraint:

- Constraint on the response time available to compute a motion (which is a function of the dynamicity of the environment).
- Constraint on the validity duration of the motion planned (which is a function of the validity duration of the predictions).

Accordingly, in a highly dynamic environment, one needs to be able to plan motions fast but one does not need to be able to plan motion very far in the future. This is precisely what iterative trajectory planning (ITP) is about: ITP *iteratively* computes a *partial motion* at a given frequency.

ITP is an attempt to bridge the gap that exists between motion planning (wherein a complete motion to a goal is computed once) and navigation (wherein only the next move is computed). ITP operates in the time-state space (TSS) of the system [54][55]. TSS is the appropriate framework to address motion planning with dynamics constraints such as moving obstacles and the dynamics of the system. Given the goal and the prediction of the moving obstacles' future behaviour, TSS is explored until a given time horizon is reached. This time horizon is determined by both the environment dynamicity and the prediction validity duration.

In this framework, two issues arise: what about the system safety beyond the time horizon, and what about the convergence toward the goal? As far as the second question is concerned, 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). 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*section 6.2.5).

In addition to that, we have started to explore the problem of the coupling of the ITP level with the control level of the system (Ph.D. topic of Stéphane Petti).

6.2.4. *Inevitable Collision States*

Participants: Thierry Fraichard, Joël Schaerer.

In 2002, we introduced the novel concept of *inevitable collision states* (ICS) and the companion concept of *inevitable collision obstacle* (ICO). 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. Similarly, an ICO is defined as the set of inevitable collision states yielding a collision with a particular obstacle.

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) [48]. 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.

2003 has been mostly dedicated to further the exploration of the ICS and ICO concepts. A number of properties that are fundamental for their characterisation have been established. In particular, we demonstrated an approximation property which is of a vital practical value since it shows how to compute a conservative approximation of an ICO by considering a subset only of the whole set of possible future trajectories of the robotic system. All these results have been presented at the 2003 IEEE-RSJ Int. Conf. on Intelligent Robots and Systems in an article [17] that was later selected for possible publication in a special issue of the Advanced Robotics journal.

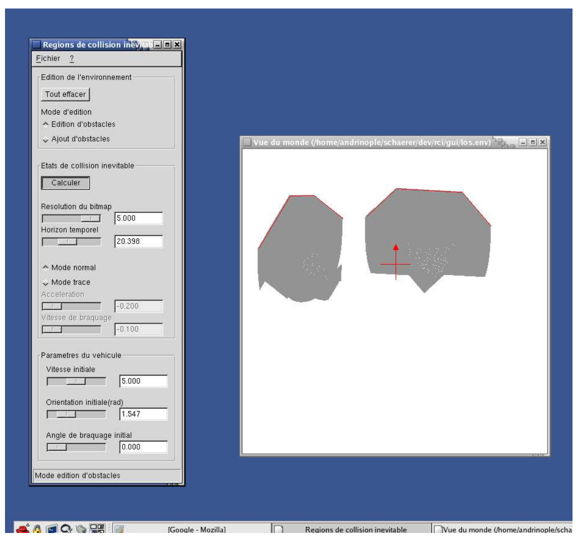


Figure 10. User interface window (left) and output window (right) of the ICO computing software.

We have also developed a software module to compute the ICOs for arbitrary robotic systems and obstacles [42]. Fig. 10 illustrate the user interface and the output of the ICO computing software.

6.2.5. Non Linear Velocity Obstacles

Participants: Frédéric Large, Christian Laugier, Sepanta Sekhavat.

Work on the NLVO (Non-Linear Velocity-Obstacles) has been initiated in 2001 [61], 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 obstacles. 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 [4]. 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 doesn't loose any possible solutions and takes into account the dynamics of the world.

Two navigation methods have been derived from the NLVO [4]: The first method 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 choosen by a heuristic function aiming at optimizing 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 unpredictable obstacles (thanks to the algorithm used to update the tree). The results point out two main advantages of the NLVO: the rapidity of the computation and the intrinsic anticipation of the future collisions.Current work aims at integrating this approach into the ITP paradigm. We also plan to make use of a probabilistic formulation of NLVO.

6.3. Probabilistic Inference and Decision

6.3.1. Reflexion on bayesian fusion

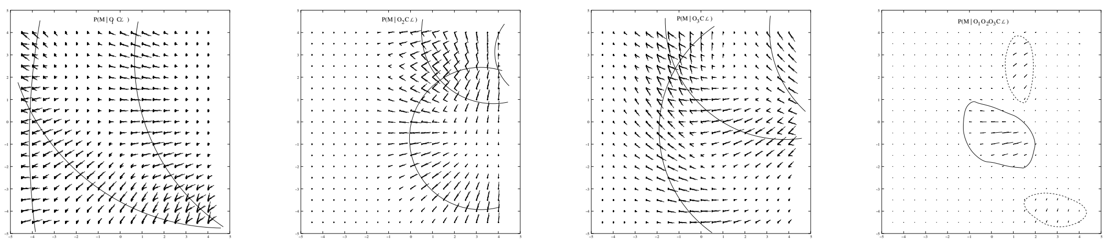
Participants: Cédric Pradalier, Francis Colas, Pierre Bessiere.

This part of our work was dedicated to the design of a fusion process, in the Bayesian Programming framework. We call "a fusion process" the activity of computing a variable A knowing a set of observations Oi, and knowing a binary relation between A and each Oi. For instance, localization of a mobile robot using a set of landmark observation is a fusion process. In the Bayesian framework, such a process can often be expressed as a product of elementary probability distributions. Nevertheless, in some case, expressing Bayesian fusion as a product is not directly possible. This is the case for instance when trying to express a command fusion, i.e. trying to control a robot using multiple control models. We have shown that expecting a fusion result as a product can lead us to use a specific modelling of our system, and of the fusion process. Fig. 12 shows how probabilistic fusion can be used to compute robot localization with implicit data association. Fig. 11 shows how obstacle avoidance can also be expressed as a bayesian inference problem: each sensor restricting command domain in order to verify system security. This work has been submitted partly to MaxEnt Conference ([27]) and partly to IROS'03 Conference ([26]).

6.3.2. Perceptual servoing on a sensori-motor trajectory.

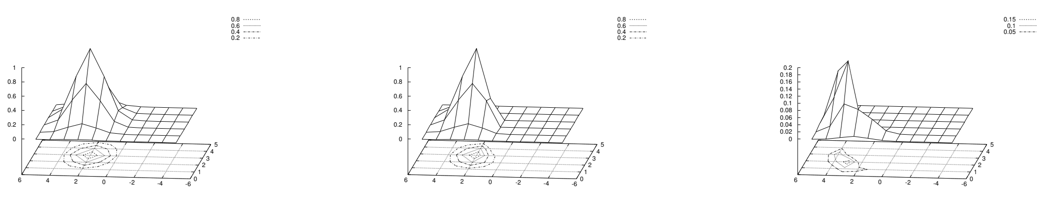
Participant: Cédric Pradalier.

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 tracking (or relative localization), trajectory tracking servoing loop, obstacle avoidance



Observation 1 | Observation 2 | Observation 3 | Fusion result

Figure 11. Localization by fusion



Desired | knowing D_2 | knowing D_6

Figure 12. Obstacle avoidance by fusion

and self-diagnosis with respect to localization hypothesis. Preliminary experimentations were performed, in simulation and on the real robot, showing the validity of the approach. This work is to be submitted in next ICRA Conference.

6.3.3. Bayesian Robot Programming

6.3.3.1. Bayesian Programming of robotic arms.

Participants: Ruben Garcia Senen, Emmanuel Mazer.

This works relates to the Bayesian programming robotic arms equipped with a stereoscopic vision system. The implementation of a task of pick-and-place of an object is given as example to evaluate the approach. This task brings into play geometrical models of the arm, of the stereoscopic vision system and of manipulated objects. The associated uncertainty with the geometric models, the sensors of the robots and the system of vision are taken into account.

6.3.3.2. Relevant information selection in robot perception

Participants: Pierre Dangauthier, Anne Spalanzani, Pierre Bessiere.

Information sensed by a robot evolving in a real environment is basically too large and uncertain. Therefore, it is difficult to deal with all this information and to extract information necessary for performing a given task.

We have studied different methods of information selection in order to reduce the amount of information and we have looked for existing correlation between the task the robot has to perform and the information given by his sensors.

We have tested different methods based on entropy and genetic algorithms on data coming from a simulator programmed by Pierre Dangauthier. Then we have compared these methods with different criteria such as performances and computational cost.

Encouraged by the first results, we started to refine the more promising methods and to test them on a real robot. We have chosen the Biba robot to go through more experiments (see next paragraph).

6.3.3.3. Behaviors demonstration using the BIBA robot.

Participants: Carla Koike, Pierre Bessiere.

A particular task of the BIBA European project is to demonstrate an indoor robot operating twenty four hours a day. The objective is to assemble several behaviors inspired by animal behaviors, as well as some working tasks, as guidance, postman, imitation and so on.

This work is motivated by the need to study in detail how to conceive and implement a complex task using the Bayesian approach. The objective is to experimentally test some possible answers to important unsolved problems such as: how to reuse a set of already developed reaction behaviors ? How do calculations scale up in relation to time and memory ?

During this year, the obstacle avoidance problem was considered ([22] and [23]) as well as using an inspired biological approach for describing behaviors in order to specify and, lately, evaluate results. Also, a homing strategy using Bayesian programming was developed.

6.3.4. Learning Bayesian Behaviors

Participants: Ronan Le Hy, Anthony Arrigoni, Pierre Bessiere.

The work initiated last year on the use of bayesian behavior models for virtual characters. A first work has been done in order to learn bayesian models for video game characters using natural game controls and demonstrations. A synthesis of this work was published in [30].

We have also explored the possibility of introducing reinforcement learning into these models, as a way to attain more adaptive behaviours [31].

A more general work on the pecularities of bayesian programming applied to virtual characters has also been pursued in collaboration with the Evasion (GRAVIR/INRIA Rhône-Alpes) and Siames (IRISA) groups, as part of a ROBEA project. It has lead to the development of a common platform (13) for the control of virtual characters, and a common publication [18].

Figure 13. Virtual flock of sheep using the OpenMASK platform

6.3.5. Methods and applications for Bayesian inference

Participants: Kamel Mekhnacha, Juan-Manuel Ahuactzin Larios, Hubert Althuser, Pierre Bessiere, Emmanuel Mazer, Olivier Aycard.

6.3.5.1. New algorithms for inference.

This year, we proposed new improvements of the underlying inference algorithms of ProBT Bayesian Inference Engine (BIE). These improvements concern both the symbolic simplification and the numerical evaluation phases:

- Construction of the evaluation tree for a given inference problem with the possibility to optimize over computation time or memory use.
- Using the evaluation tree to construct (or to update) a numerical representation of this target distribution.

These algorithmic improvements are the result of the “Mathstic” scientific collaboration project between CNRS and Marne-La-Vallée University. This work is to be submitted to JAIR journal.

6.3.5.2. 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)

6.3.5.3. 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).

6.3.5.4. Applications in relation with the ProBayes start-up.

- **Application for Stock Exchange**
  This work concerns the application of Bayesian learning and inference methods in Stock Exchange. It's a collaboration project between Joseph Fourier University and the Société Générale Asset Management (SGAM) team.The result of this collaboration is a Bayesian tool called AGGREGATOR (see Figure 14). This tool is intended to help SGAM stock market experts and traders to aggregate a set of financial indicators when deciding about a future share basket selection.The main idea of this tool is to use an history data base to learn the relation (distribution) between the response for each indicator and the actual performances of shares after a given period. Then, for a given share, these individual distributions are aggregated using a Bayesian scheme to get a probability distribution on its sale/purchase options. The obtained results are very promising and the system is actually in use by the SGAM team.
- **Application for UPS faults detection and preventive maintenance**
  This application is concerned with the development of a Bayesian tool for preventive maintenance of UPS systems (see Figure 15). The aim of such systems is to increase the availability and uptime of mission-critical applications or processes by ensuring the availability and the stability of the electric current of the network. Therefore, preventive maintenance is a central issue for the reliability of these systems. This Bayesian preventive maintenance tool is the result of an RNTL collaboration project (called AMIB-E) between INRIA and two industrial partners, namely: MGE UPS SYSTEMS and TEAMLOG. The first prototype (see Figure 15) 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 UPS systems.

7. Contracts and Grants with Industry

7.1. Biba

European project IST-2001-32115, "Bayesian Inspired Brain and Artefacts", (http://www.cybercars.org) [November 2001-November 2005].

The twin technological and scientific goals of the BIBA project are:(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.

Our team is coordinator of the project. Our partners are University College of London (Gatsby Unit), University College of Cambridge (Physiology lab), Collège de France (Laboratory of Physiology of Perception and Action), Ecole polytechnique fédérale de Lausanne (Autonomous Systems Lab) and the Massachusetts Institute of Technology (Non Linear Systems Lab)

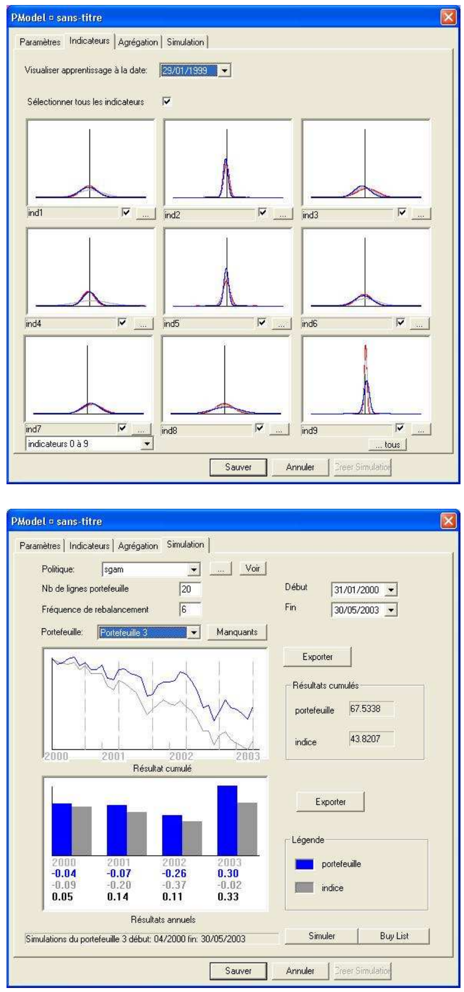


Figure 14. AGGREGATOR: a Bayesian tool for share baskets selection.

Figure 15. AMIB-E P1: a first prototype tool for preventive maintenance of UPS electronic components.

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.

7.2. CyberCars

European project IST-2000-28487 CyberCars, "Cybernetic Cars for a New Transportation System in the Cities", (http://www.cybercars.org) [August 2001-July 2004].

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 eMotion in CyberCars relates to driving automation.

7.3. Carsense

European project IST 1999-12224 CarSense, “Sensing of Car Environment at Low Speed Driving” (http://www.carsense.org) [January 2000-December 2002]. 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). eMotion is in charge of the data fusion subject.

7.4. Profusion

European project, PreVENT Programme(Preventive and Active Safety Applications) Profusion, “Project for Robust and Optimised Perception by Sensor Data Fusion” [2004-2005]

By means of a horizontal approach through Preventive Safety functions requirements, and of the integrated assessment of the potential and performance of sensor technologies and sensor data fusion, the overall objective of ProFusion is to set the bases for Perception Solutions that will go beyond current state-of-the-art.As described here, ProFusion is the first stage of a horizontal activity within IP PReVENT, that will aim 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. The Profusion consortium includes 70 partners coming from industry and public research.

7.5. Puvame

National project, Predit Programme Puvame "Protection des Usagers Vulnérables par alarme et Manoeuvre d'Evitement" [October 2003-September 2004]

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) and Imara project (Inria Rocquencourt; Michel Parent), Ecole des Mines de Paris (EMP), INRETS, Intempora, Probayes, Robosoft, Connex

7.6. Mobivip

National project, Predit Programme Mobivip "Véhicules Individuels Publics pour la Mobilité en centre ville" [October 2003-September 2004]

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.

7.7. ARCOS

National project, Predit Programme Arcos"Action de Recherche pour une COnduite Sécurisée" [June 2003-December 2004]

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!). eMotion 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).

7.8. Kelkoo

Industrial project, ProBayes start-up [October 2003-March 2004]

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.

7.9. AMIB-E

This RNTL collaboration project (called AMIB-E) between INRIA and two industrial partners,(namely: 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.

7.10. Visteo

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.

8. Other Grants and Activities

8.1. Other Grants

8.1.1. Robea project: a speech-gifted android.

This Robea project gathers three partners: ICP, INRIA and University of Texas At Austin. 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.

8.1.2. Robea project: Bayesian models for motion generation.

This project proposes new forms of interaction between man 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 reaction abilities to certain situations. To achieve these goals, we gather in this project specialists teams of the different fields: e-Motion (INRIA the Rhône-Alpes and GRAVIR) for its expertise on the Planning of Movement, Bayesian Inference and its experience in Robotics; SIAMES (IRISA) for the animation of virtual characters and the modeling of the environments in which they evolve; and EVASION (INRIA Rhône-Alpes and GRAVIR) for its know-how in synthesis of natural animated and interactive scenes.

8.1.3. Robea project Parknav Interpretation of Complex Dynamic Scenes and Reactive Motion Planning.

The goal of this Robea 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. The project started in October 2002 for a three year duration. The partners are eMotion (leader), Movi and Prima from Inria Rhône-Alpes, Vista from Irisa and the Laas. 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.

8.1.4. NavDyn project.

The NavDyn project is a joint Lafmi project between eMotion and the Center for Intelligent System (CSI) of the Mexican Technological Instituteof Monterrey (ITSEM). It started in October 2003 for a two year duration.The project full name:"Autonomous Navigation in Dynamic Environments",describes its goal. CSI Itesm is in charge of the vision part of the project (detection and tracking of moving objects using an off-boardpan-tilt video camera) whereas eMotion is in charge of the autonomous motion part (taking into account moving objects with unknown futurebehaviour). The midterm evaluation that took place in November 2003 was successful and the project was prolongated.

8.2. International collaborations

8.2.1. Pacific and South Asia

8.2.1.1. Collaboration with Japan.

Since October 1997, eMotion 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.

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 submitted 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.

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 eMotion 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.

8.3. Visiting scientists

In 2003, eMotion welcomed the following visiting scientists:

- Prof. Oussama Khatib, Professor in Stanford University.

9. Dissemination

9.1. Dissemination

- C. Laugier and J-M. Ahuactzin have participated to the organization to the summer school "Image and Robotics" in July 2003 at Puebla, Mexico.
- C. Laugier participated to the organization committees of these international conferences: IEEE Int. Conf. on Robotics and Automation (ICRA’2003), IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS’2003), Int. Conf. on Field and Service Robotics 2003 (FSR’03), Int. Symposium on Surgery Simulation and Soft Tissue Modelling (ISSTM’03).
- C. Laugier is a member of the steering-advisory committee of IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS) since 1997, and since 2000 of the advisory committee of Int. Conf. on Control, Automation, Robotics and Vision (ICARCV).
- C. Laugier is a member of the steering committee of the robotics European Network EURON, and also a member of the French-Korean committee of the French ministry of Foreign Affairs.
- C. Laugier is a member of the scientific committee of (1) the national programme in robotics ROBEA, (2)the CNRS RTP17 committee (Autonomous and Communicating Robotics) and (3) the scientific committee of PREDIT Group 9.

9.2. Academic Teachings

In addition to ponctual academic lectures, the members of eMotion have tought the following lectures:

- Lecture“Motion planning”: Summer school "Image and Robotics", Puebla, Mexico [July 2002]. *Teachers: J-M. Ahuactzin et Th. Fraichard.*
- Lecture“Techniques avancées en planification de mouvement: DEA “Imagerie, Vision, Robotique” de l’INPG, Grenoble, (FR). *Enseignants: Th. Fraichard.*
- Lecture “Introduction to roboticsand current research issues”: Summer school "Image and Robotics", Puebla, Mexico [July 2002]. *Teachers: C. Laugier.*
- Lecture “Bayesian robot programming”: Summer school "Image and Robotics", Puebla, Mexico [July 2002]. *Teachers: O. Aycard*
- Lecture “Robotics and motion autonomy”: DEA “Imagerie, Vision, Robotique” INPG, Grenoble, (FR). *Teacher: C. Laugier.*
- Lecture “Basic tools and models for Robotics”: Cnam Grenoble. *Enseignant: C. Laugier et J. Troccaz.*

9.3. Conference and workshop committees, invited conferences

The dissemination of results and the active participation to international scientific events (see bibliography) are two essential activities of eMotion . Concerning the invitations to scientific events:

- C. Laugier participated to a conference on the topic "Motion Planning in Artificial systems" within the seminar "Motion at Human Scale" in Grenoble (January 2003).
- C. Laugier participated to a public conference in Lyon cultural center on the subject " Future of Robotics" in March 2003.
- P. Bessiere has been invited to a public conference during "la Semaine du Cerveau" in Grenoble, May 2003.

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