INRIA, Evaluation of Theme NumA

1 Administrative aspects

Project-team acronym : e-Motion

Project-team title : Geometry and probability for motion and action

Scientific leader : Christian Laugier

Research center : Rhône-Alpes

Common project-team with : GRAVIR Laboratory (CNRS, INPG, UJF)

Personnel (September 2001, in the "Sharp" project)

	Misc.	INRIA	CNRS	University	**Total**
DR (1) / Professors		1	1		**2**
CR (2) / Assistant Professors		2			**2**
Permanent Engineers (3)					
Temporary Engineers (4)		2			**2**
PhD Students	4		2	2	**8**
Post-Doc.		4			**4**
Total	**4**	**9**	**3**	**2**	**18**
External Collaborators			1	1	**2**
Visitors (> 1 month)				2	**2**

(1) "Senior Research Scientist (Directeur de Recherche)"
(2) "Junior Research Scientist (Chargé de Recherche)"
(3) "Civil servant (CNRS, INRIA, ...)"
(4) "Associated with a contract (Ingénieur Expert or Ingénieur Associé)"

Personnel (September 2004)

	Misc.	INRIA	CNRS	University	**Total**
DR / Professors		1	1		**2**
CR / Assistant Professor		2	1	2	**5**
Permanent Engineer					
Temporary Engineer		3			**3**
PhD Students	4	1		3	**8**
Post-Doc.		1			**1**
Total	**4**	**8**	**2**	**5**	**19**
External Collaborators					
Visitors (> 1 month)					

Comments : *1 DR (Emmanuel Mazer) is currently working in our new start-up "Probayes", and 1 CR (Sepanta Sekhavat) is working in Iran for a period of two years (since February 2003).*

Changes in staff

No change since the project creation (February 2004).

Current composition of the project-team (September 2004):

- Christian Laugier, DR Inria
- Emmanuel Mazer, DR CNRS (currently at Probayes)
- Pierre Bessiere, CR CNRS
- Thierry Fraichard, CR Inria
- Sepanta Sekhavat, CR Inria (currently in Iran)
- Olivier Aycard, Associate Professor UJF
- Anne Spalanzani, Associate Professor UPMF
- Julien Diard, External collaborator (currently at LPPA, collège de France)
- Juan-Manuel Ahuactzin Larios, Temporary Engineer (Biba IST project)
- Olivier Malrait, Temporary Engineer (Biba IST project)
- Fernando De la Rosa, Temporary Engineer (Puvame Predit project)
- Christophe Coué, Postdoc (Profusion IST project)
- Miriam Amavicza, PhD student (Mexican Conacyt/Sfere fellowship)
- Alejandro Dizan Vasquez Govea, PhD student (Mexican Conacyt/Sfere fellowship)
- Francis Colas, PhD student (MENESR fellowship)
- Pierre Dangauthier, PhD student (MENESR fellowship)
- Carla Koike, PhD student (Brazilian Capes fellowship)
- Ronan LeHy, PhD student (MENESR fellowship)
- Manuel Yguel, PhD student (CIFRE fellowship with Probayes)
- Stéphane Petti, PhD student (Industrial fellowship from AW Europe)

Current position of former project-team members (including PhD students during the 2000-2004 period):

Not applicable.

Last INRIA enlistments

None.

Other comments :

The project *e-Motion* was created in February 2004. It is issued from the *Sharp* project and the *Laplace* team of the Leibniz laboratory at IMAG.

2 Scientific aspects

2.1 Keywords

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

2.2 Research fields

The project-team *e-Motion* addresses the following three strongly correlated research fields, by combining the respective advantages of *computational geometry* and of the *theory of probabilities* :

- *Multimodal and incremental modelling of space and motion* : modeling the various aspects of the real world; combining a priori knowledge and flows of perceptive data; predicting objects motions and behaviors.

- *Motion planning for the physical world* : constructing incrementally efficient space-time representations; iterative motion planning under kinematics, dynamics, and time constraints.

- *Probabilistic inference for decision* : developping models and computational tools for bayesian programming.

2.3 Project-team presentation overview

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

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

- *Multimodal and incremental modelling of space and motion.* The basic idea consists in continuously building (using preliminary knowledge and current perceptive data) several types of models having complementary functional specialisations (as suggested by neurophysiologists).

- *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.

- *Probabilistic inference for decision.* The problem to solve is to be able to correctly reason about both the current knowledge of the system and the associated uncertainties. This will be done using the bayesian programming principle.

2.4 Scientific foundations

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 includes complex multimodal data, are continuously changing and partially unpredictable, and generate complex interactions with humans. This means that *appropriate decision-making processes* taking into account these characteristics have to be designed, implemented and experimented in real situations. Such processes have to be efficient and robust enough for making it possible to meet the required reactivity characteristics, while beeing able to make appropriate decisions from complex and incomplete data and knowledges, i.e. by reasoning about a combination of partial a priori knowledges, of some incremental experimental data (including sensory data), and of some hidden variables. This means that new models and algorithms have to be designed for beeing able to formalise the intrinsic *"incompleteness"* of the problem, and to better model the intricate *"complexity"* of the real world.

The objective of the *e-Motion* project-team is to find formal and practical solutions to these difficult problems, still very little addressed by our scientific community. Our bet is that such an approach 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.

2.5 Application domains

The main applications of this research 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).

2.6 Main contributions

2.6.1 Multimodal and incremental modeling of space and motion

SLAM in changing environments

We have extended our previous SLAM (Simultaneous Localization and Mapping) approach designed for static environments, in order to be able to operate in some changing environments such as a car park (i.e. where the occupancy of the parking lots changes anytime). The first results has been obtained using a sick laser and a global consistency branch and bound method (for extracting hypothesised parked cars)[6].

Bayesian maps for robot navigation

The basic idea is to combine probablistic and biomimetic models, in order to be able to merge models built from different sensory modalities (obtained during a learning phase), and to build hierarchies of sensori-motor models. This is done using "superposition" and "abstraction" operators designed for combining probabilistic models of space[2].

Future motion prediction for surrounding objects

Navigating or planning motions in an environment including uncontrolled moving entities, requires to reason about the future behavior of the surrounding objects. Most prediction techniques found in the literature are limited to short-term prediction only (a few second at best). Our approach consists in trying to obtain a more long-term motion prediction for the moving objects, by combining a "learning phase" for determining the typical motion patterns, and a "prediction phase" for determining at any time what is the more likely behavior of the object considered[69].

Dynamic scene interpretation using bayesian data fusion
The addressed problem is to exploit various sensing modalities in order to obtain at any time a robust estimation of the dynamic characteristics (e.g. position and velocity) of the moving entities of the scene (e.g. the traffic participants in the case of an ADAS system –Advanced Driver Assistance System–). This problem can be seen as the combination of a multi-target tracking problem and of a short-time prediction problem. Our approach for solving it consists in continuously estimating the occupied and free space of the robot control space, using our new concept of *bayesian occupancy filter*. We have recently applied for patent of this concept[1]

2.6.2 Motion planning for the physical world

Motion planning for a bi-steerable car using differential flatness
The Cycab is a special class of four-wheeled vehicle equipped with double steering axles. Classical approaches designed for car-like vehicles cannot be applied for planning and controlling the motions of such a vehicle (since the related differential equations are much more complex). We have used the theory of *differential flatness* for finding an elegant solution to this problem, by consecutively showing that the Cycab is a flat system, by constructing an explicit model for characterizing the flat outputs, and by designing and implementing a motion planner and a controller based on these results[3].

Safe navigation using bayesian programming
The problem addressed is to avoid the sensed (stationary or moving) obstacles, while executing a pre-planned motion for the Cycab. The basic idea is to combine our flat control law (see previous section) which is very sensitive to perturbations, with a bayesian trajectory tracker designed for "deforming" locally the trajectory (shape and/or associated velocities) when an unforeseen obstacle is on the Cycab way. This approach has been experimented on the INRIA car park, among some pedestrians[6].

Obstacle avoidance using Non-linear Velocity Obstacles (NLVO)
The previous approaches can hardly been applied when the robot is moving at high speed amidst a significative number of moving obstacles. Our new concept of *NLVO* allows to compute in real time (thanks to an original computational model designed in the complex space) the colliding velocities associated to each moving obstacle, and the time to collision for any admissible control of the robot. This approach can be seen as a generalisation of the Velocity Obstacle approach proposed by Shiller & Fiorini a few years ago. It has been applied for implementing a robust obstacle avoidance system (e.g. for performing a reactive safe navigation among a large set of moving entities). We are currently trying to integrate this idea in the Iterative Trajectory Planning paradigm (see next section). We have applied for a patent on this idea[4].

Iterative trajectory planning (ITP)
As previously mentionned, motion planning in an environment including uncontrolled moving entities requires to reason about the future behavior of the moving obstacles. Consequently, motion planning faces a double contraint on response time for the planner (i.e. time is limited) and on the validity duration of the computed solution (related to the validity duration of the predictions). This means that we need to plan motions fast, but one does not need to be able to plan motion very far in the future. This is why we have proposed the *ITP* paradigm, which consists in *iteratively* computing *partial motion* at a

given frequency, in the *time-state space* of the system associated to a given *time horizon*. At this state of the research, only a few theoretical issues have been addressed concerning the convergence and the safety beyond the time horizon (using the concept of *inevitable collision state*). Some practical interesting results have also been obtained by combining this paradigm with the *NLVO* concept described in the previous section[4].

2.6.3 Probabilistic inference for decision

Models and tools for bayesian inference

Bayesian inference is a NP-hard and efficient methods are still required for beeing able to process complex data. We have proposed an improvement of the underlying inference algorithms of our *ProBT* bayesian inference engine. This improvement concerns both the symbolic simplification and the numerical evaluation phases; it is based on an original construction and exploitation of the evaluation tree, allowing to optimize the computation time or the required memory size. A parallel version of the *ProBT* bayesian inference engine has also been developed in collaboration with the *Apache* project-team (for SMP or cluster). Learning from data is also a central issue in bayesian programming; we have started to develop methods for estimating the probability distribution of the free parameters, the learning of variables dependencies beeing an open problem. Two industrial applications in the domain of stock exchange (with SGAM) and of faults detection for preventive maintainance (with MGE UPS) have been developed in cooperation with our start-up *ProBayes*.

Bayesian robot programming

Several aspects of robot programming have been addressed using the bayesian programming paradigm:

- **Perceptual servoing on a sensori-motor trajectory.** A sensori-motor trajectory is described by a sequence of exteroceptive perceptions (sensors) associated with proprioceptive data (motors). The problem addressed is to track reactively (i.e. while avoiding some obstacles if necessary) such a previously learned sensori-motor trajectory. The developed approach uses the bayesian programming paradigm for performing as robustly as possible the required functions : relative localization, trajectory tracking servoing loop, obstacle avoidance, and self-diagnosis with respect to localization hypotheses. The approach has been experimentally validated on the Cycab[6].
- **Information selection and reactive behaviors.** Information sensed by a robot evolving in a real environment is both too large and uncertain for beeing easily exploited by the navigation function and the related reactive behaviors. The first problem is to extract relevant information for the task that the robot is currently performing; some preliminary results have been obtained using methods based on entropy and on genetic algorithms. The second problem consists in combining several behaviors inspired by biology, in order to perform robustly a variety of tasks. Some interesting results using bayesian programming have been obtained and experimented on the BIBA robot (for obstacle avoidance and homing strategies)[36, 56].

Learning bayesian behaviors

Bayesian programming has been used for modeling the behaviors of virtual characters in video games, and for developing a learning procedure allowing to construct such models from the observation of the natural game controls. More adaptive behaviors have also been obtained using a reinforcement learning procedure. This work has been done in collaboration with the *Evasion* and *Siames* project-teams[12, 52].

2.7 Project-team positioning

The *e-Motion* project-team collaborate with most of the INRIA project-teams working on connex or complementary thematics. None of these project-teams is directly working on similar modeling and planning problems, under both the incompleteness and space-time constraints we are dealing with. Our approach combining geometry and probability for solving such problems is also original.

The collaborations inside INRIA relies either on complementary thematics such as computer vision (*Movi, Prima, Vista*) or robot control (*Icare*), or on common work done in the scope of large projects such as the "automated road" (*Imara, Visa, Icare, Vista, Maia, SED service of INRIA Rhône-Alpes*). Currently, we do not collaborate with some other research-teams such as *Bipop* or *Demar* who mainly work in the field of control of non-linear dynamical systems (with a special emphasis on human walking).

We are also collaborating (in the scope of some national or european projects) with the main French and foreign research teams working on close or similar topics: *LAAS Toulouse* (safe navigation of mobile robots), *Lasmea Clermont-Ferrant* (vision and control problems for automatic vehicles), *Ecole des Mines de Paris* (vision for car driving assistance and differential flatness), *EPFL Zwitzerland* (SLAM and control for mobile robots). One of our main competitor is the Robotics laboratory of Stanford University (S. Thrun and JC. Latombe) who are working on some similar topics under a close philosophy; at the moment, we have no formal collaboration with them on that topics (only some informal exchanges and cross visits).

2.8 Publications

	01	02	03	04
PhD Thesis	1		6	2
H.D.R (*)				
Journal	5	3	3	7
Conference proceedings (**)	11	10	22	14
Book chapter	3			1
Book (written)				
Book (edited)				
Technical report	8	13	13	6
Deliverable				

(*) HDR Habilitation à diriger des Recherches
(**) Conference with a program committee

Indicate five main journals in which scientific staff members publish their results:

1. International Journal of Robotics Research (IJRR)
2. IEEE Transactions on Robotics and Automation (ITRA)
3. Robotics and Autonomous Systems (RAS)
4. Advanced Robotics
5. Autonomous Robots

Indicate a maximum of five principal conferences where scientific staff members published their results on a regular basis:

1. IEEE International Conference on Robotics and Automation (ICRA)

2. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)
3. International Symposiom of Robotics Research (ISRR)
4. International Symposiom of Experimental Robotics (ISER)
5. International Conference on Field and Service Robotics (FSR)

2.9 Software

2.9.1 Advanced software

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

ProBT. Formerly known as *OPL*, *ProBT* is a C++ library for developing efficient Bayesian software. It is available for Linux, Unix, PC Windows (Visual C++), MacOS9, MacOSX and Irix systems. The ProBT library has two main components: (i) a friendly Application Program Interface (API) for building Bayesian models, and (ii) a high-performance Bayesian Inference Engine (BIE) allowing to execute all the probability calculus in exact or approximate way. *ProBT* is now commercialized by our start-up *Probayes*; it represents the main Bayesian programming tool of the *e-Motion* project-team, and it is currently used in a variety of external projects both in the academic and industrial field.

Cycab Simulator. In order to perform pre-test and to provide help for Cycab developers, a Cycab simulator has been developed. This simulator is intended to simulate hardware and low-level drivers, in order to produce a temporal behaviour (refresh frequency, scheduling...) similar to what can be found on the Cycab. Furthermore, a hierarchy of C++ classes has been developed in order to keep a consistent interface between the simulated CyCab and the real one. Applications written and tested on the simulated robot can then be settled to the real one with only minor modifications (instantiating one class or the other). Sensors and environment are also simulated, so that complete applications can be developed on this test bed. Finally, we also provide developer with an TCP/IP controllable Cycab, consistent with simulated and real Cycab in term of C++ interface. The Cycab Simulator is currently widely used by the researchers of the *e-Motion* project-team; it has also been used in a collaboration with the RIA team (LAAS, Toulouse), and with the LAG laboratory (IMAG, Grenoble). A recent extension of the system is also used for student home-work in the scope of robotics courses (Summer school on image & robotics 2004, and Master IVR at ENSIMAG Grenoble 2004-05).

VisteoPhysic. This library provides efficient tools for deformable object simulation. It includes the Finite Element Method (FEM) and the Long Element Method (LEM) deformable models for physical simulation. It also has interactions models for collision detection, exact distance computation, and contact localization of three-dimensional polygonal objects. These objects can be concave or convex, rigid or deformable. This library is numerically robust - the algorithms are not subject to conditioning problems, and requires no special handling of nongeneric cases. *VisteoPhysic* has been implemented in standard C++ and relies heavily on STL in order to be as fast and memory efficient. The library was developed in collaboration with XL-Studio and is patented under the french APP patent #IDDN.FR.001.210025.000.S.P.2004.000.10000

2.9.2 Prototype software

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

2.10 Collaborations

2.10.1 Collaborations with other INRIA project-teams:

We are collaborating with the following project-teams within the scope of several national (e.g. Predit, Robea) or european (e.g. IST Cybercars, IST Prevent) projects[1] :

Movi,Prima, Vista : Vision based world reconstruction and object tracking

Icare, Visa, Imara, Maia, SED : Robust control and navigation for the Cycab

Evasion, Siames : Bayesian behaviors for virtual autonomous entities

Comment : Thierry Fraichard and Christian Laugier are also co-directing two PhD students (Mikael Kais and Stephane Petti) of the *Imara* project-team.

2.10.2 Collaborations with French research groups outside INRIA:

We are also collaborating with the following French research groups within the scope of several national (e.g. Predit, Robea) or european (e.g. NoE Euron, IST-FET Biba) projects[1] :

Inrets Lyon, EMP(Laurgeau), Lasmea Clermont-Ferrant : HMI and vision for driving assistance

EMP(Rouchon) : Differential flatness

LAAS Toulouse, UTC Compiègne : Safe navigation for a mobile robot

ICP Grenoble : Bayesian models for a speech-gifted android

LPPA collège de France, Paris : Biologic plausibility of bayesian inference

[1]informal cooperation are not mentionned.

2.10.3 Collaboration with Foreign research groups:

We are also collaborating with the following Foreign research groups within the scope of european projects (e.g. NoE Euron, IST-FET Biba) or of formal cooperation agreements including exchanges of students and of researchers[1] :

EPFL Switzerland, Univ. College of London UK, Univ. College of Cambridge UK, MIT USA : Bayesian inspired brain and artefacts (IST BIBA).

ITESM Monterrey Mexico : Autonomous navigation in dynamic environments (France-Mexico *NavDyn* project).

ITESM Monterrey, ITESM Cuernavaca, UDLA Puebla ... : Mexico-France network on Image and Robotics (with the financial support of the LAFMI Mexico-France laboratory).

NTU Singapore : Control and perception for intelligent vehicles (collaboration agreement, with the financial support of the French ambassy in Singapore).

NUS Singapore : Biologically inspired robots for reactive navigation (PICS CNRS involving the LPPA Collège de France of Alain Berthoz).

Riken Tokyo : Multi-robots systems (with a financial support of the French ambassy in Japan during the first years of the project).

Korea : SLAM and motion planning in dynamic environments (*SafeMove* project supported by the STAR France-Korea programme).

2.11 Specific hardware for experimental purpose (if relevant):

Two Cycabs equipped with various sensors (cameras, sick laser, US sensors ...)

BIBA mobile robot

Koala mobile robot

Set of fix and pan-tilt cameras on the car park of INRIA Rhône-Alpes

2.12 Specific software for experimental purpose (if relevant):

Cycab simulator

Cycab control tools (including Orccad and Syndex)

ProBT system for bayesian programming

RTMaps toolbox for perception system prototyping

2.13 Industrial collaborations:

IST "Carsense" [January 2000-December 2003]

European project IST 1999-12224 CarSense, "Sensing of Car Environment at Low Speed Driving". A consortium of 12 european car manufacturers, suppliers and research institutes are together under the head of the CARSENSE programme. This programme concerns the development of a sensor system, having the capability to give sufficient information on the car environment at low speeds in order to allow low speed driving. This project includes european industrials from car industry (Renault, BMW, Lucas Varity, Thomson Detexys, Ibeo, etc.) and research institutes (Inria, Inrets, Livic). *e-Motion* was in charge of the data fusion subject.

IST "CyberCars" [August 2001-July 2004]

European project IST-2000-28487 CyberCars, "Cybernetic Cars for a New Transportation System in the Cities". 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* relates to driving automation.

IST "Profusion" [2004-2008]

European IP project, *PreVENT* Programme(Preventive and Active Safety Applications); *Profusion* subproject, "Project for Robust and Optimised Perception by Sensor Data Fusion".The *PreVENT* consortium includes 70 partners coming from industry and public research (including the main car constructors), and *e-Motion* is the leader of the *Profusion* subproject.

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.

Predit "Puvame" [October 2003-September 2005]

National Predit Programme *Puvame* "Protection des Usagers Vulnérables par alarme et Manoeuvre d'Evitement". The partners of the project are: Inria *e-Motion* (coordinator), Inria *Imara*), Ecole des Mines de Paris, INRETS Lyon, Intempora, Probayes, Robosoft, Connex.

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.

Predit "Mobivip" [October 2003-September 2005]

National 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.

Predit "Arcos" [June 2002-December 2004]

National Predit Programme *Arcos* "Action de Recherche pour une COnduite Sécurisée". The aim of the project is 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!). 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). *e-Motion* is in charge of the research subject "Information synthesis and commands development".

Kelkoo [October 2003-March 2004]

Industrial project involving our *ProBayes* start-up. Kelkoo the european leader of price comparison on Internet proposes to its customers a service making it possible to compare the offers on the market. In order to propose increasingly precise information on the products Kelkoo creates a data base of these products. A very important function is the association of offers with the products of Kelkoo data base. This function already exists but requires many adjustments to take into account the inaccuracies of the different offers suggested. The aim of the collaboration of Kelkoo with INRIA is the validation of the use of an inference engine based on bayesian probabilities to carry out a matcher able "to learn" and to improve the results of the matching offer/product without requiring long and expensive adjustments.

RNTL "AMIB-E" [June 2002- June 2004]

This RNTL collaboration project 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.

PRIAMM "Visteo" [May 2000- July 2004]

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

2.14 Other funding, public, European, regional, ...:

Robea "Speech-gifted android" [2002-04]

This project gathers three partners : ICP-IMAG, University of Texas At Austin, and Inria *e-Motion*. Its objectives are the study and modelling of perception, production and learning mechanisms, in order to improve our understanding of the word and the language, and to open new ways for their automatic treatment.

Robea "Bayesian models for motion generation" [2003-05]

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 reaction 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*[2] 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).

2.15 Teaching

Lecture "Motion planning": France-Mexico Summer school on "Image and Robotics" (every year). *Teachers: J-M. Ahuactzin and Th. Fraichard.*

Lecture "Techniques avancées en planification de mouvement" (every year): DEA "Imagerie, Vision, Robotique" de l'INPG, Grenoble, (FR). *Teachers: Th. Fraichard.*

Lecture "Introduction to robotics and current research issues" (every year): France-Mexico Summer school on "Image and Robotics" (every year). *Teachers: C. Laugier.*

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

Lecture "Bayesian robot programming": France-Mexico Summer school on "Image and Robotics" (every year). *Teachers: O. Aycard.*

Lecture "Introduction to Robotics and Motion Planning" (every year), Summer school on "Automatic Control for Production Systems" de l'ENSIEG, Grenoble (FR). *Teacher: Th. Fraichard.*

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.*

Tutorial on "Autonomous mobile robots in real environments": Singapore, May 2004. *Teachers: C. Laugier and O. Aycard.*

2.16 Visibility

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

In addition to this scientific activity, some members of *e-Motion* participates to events addressed to a larger public, for instance:

- Seminar "Motion at Human Scale", Grenoble (January 2003). Talk on "Motion Planning in Artificial systems" given by C. Laugier.
- Public conference in Lyon cultural center, Lyon (March 2003). Talk on "Future of Robotics" given by C. Laugier.
- Public conference during "la semaine du cerveau", Grenoble (May 2003). Talk given by P. Bessiere.
- Seminar "TIC et mobilité", Antibes (June 2004). Talk on "Tools for automated driving" by Th. Fraichard.
- Colloquium of the French Navigation Institute, Paris (March 2004). Talk on "Intelligent transport systems" by Th. Fraichard.

The members of *e-Motion* also participates to some international committees and to the organization of conferences and summer schools :

- C. Laugier and JM. Ahuactzin are members of the steering committee of the summer school on Image and Robotics launched in 2000 in Grenoble (this summer school alternates each year between France and Mexico).
- 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. He is also a member of the following scientific committees : French-Korean committee of the French Ministry of Foreign Affairs, National programme in Robotics ROBEA, CNRS RTP17 on Robotics, and inter-ministerial PREDIT group 9 on new technologies for transport.

- C. Laugier participate every year to the organization committees of the major international conference on Robotics, in particular : IEEE International Conference on Robotics and Automation (ICRA), IEEE/RSJ Intenational Conference on Intelligent Robots and Systems (IROS), International Conference on Field and Service Robotics (FSR). He was general chair of IROS'97, Regional programm chair of IROS'00, Programme chair of IROS'02.

- T. Fraichard and P. Bessiere are regurlarly members of the programme committees of the ICRA and IROS conferences.

3 Main evolution of the objectives during the evaluation period

3.1 Planned objectives

Not applicable (project created in February 2004).

3.2 Main evolution

Not applicable (project created in February 2004).

4 Objectives for the next four years

The objectives for the next four years are directly related to the research topics described in section 2.6 (since the current contributions described in this section represents the first step towards the long term goal of the project). Most of these objectives are directly connected to some future deliverables of the research contracts we are involved in (IST-FET Biba, IST-IP Profusion, Robea Parknav, Predit Puvame ...); each individual research topic is studied by a PhD student.

Multimodal and incremental modelling of space and motion :

- *SLAM in a dynamic environments.* The objective is to be able to build an "evolutive map" taking into account both world changes and temporary obstacles; we will try to use several sensing modalities (including vision) for processing natural landmarks and for improving the robusteness of the system. A special emphasis will be put on uncertainty processing and self diagnosis (using bayesian programming).

- *Bayesian maps for sensory-motor based navigation.* Our initial theoretical work will be extended and experimentally compared to some biological theories (in cooperation with A. Berthoz laboratory); in a second step, we will try to apply this approach to one of our mobile robots equipped with several sensing modalities.

- *Future motion prediction for potential obstacles.* The objective is to integrate various knowledges in the prediction process (e.g. kinematics constaints) and to try to extend the approach to less structured scenes (e.g. in the INRIA car park).

- *Interpretation of dynamic scenes using bayesian data fusion.* This is an important topic for the development of ADAS systems. Three main research directions will be followed for extending our current approach: dealing with multi-sensor and multi-target scenarios, methods for obtaining real-time responses in large environments, and integration of a priori knowledges within the prediction phase.

Motion planning for the physical world :

- *Safe navigation using bayesian programming.* The objective is to be able to correctly combine a bayesian obstacle avoidance system (for a reactive tracking of planned trajectories) and a robust controller for the Cycab (e.g. based on flat outputs). Both data fusion problems and control problems will be addressed.

- *Iterative trajectory planning (ITP).* We will both develop the required theoretical material and the related algorithmic problems. As for the safety issue (i.e. avoiding critical situations), we will explore more deeply the two solutions respectively based on NLVO (non-linear velocity obstacles) and on the concept of "inevitable collision states". We will also explore the problem of the coupling of the ITP layer with the control layer of the system.

Probabilistic inference for decision :

- *Models and tools for bayesian inference.* We will continue to develop new algotithms for the bayesian inference (both at the symbolic and numerical levels), in order to find a good compromise between computational time and memory size. We will also work on the problem of the estimation of variable dependencies from a set of experimental data.

- *Bayesian robot programming.* We will continue the current work on three basic subproblems : safe navigation along sensori-motor trajectories, consistent information selection in large sets of sensory data, and fusion/combination of reactive behaviors inspired from biology. The last point will be studied in collaboration with the neurophysiologists involved in the BIBA project.

- *Learning bayesian behaviors.* The main objective is to study how to learn adaptive behaviors from time-dependent experimental data. In a medium term, this work will be done in scope of virtual worlds (e.g. video games), where such experimental data (i.e. virtual perception, sequences of controls, failures ...) are more easy to obtain and to process. This work will be done in cooperation with the *Evasion* and *Siames* project-teams in the scope of a Robea project.

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