



INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team Imara

*Informatique, Mathématiques et
Automatique pour la Route Automatisée*

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2. Overall Objectives

Key words: *transportation systems, environment, automated guided vehicle.*

IMARA is a "horizontal" project at INRIA. Its objective is the coordination and the transfert of all the research done at INRIA which can be applied to the the concepts of "la Route Automatisée". In particular, we will develop and transfer the results of a number of INRIA projects in the following domains:

- Signal processing (filtering, image processing,...);
- Control of the vehicle (acceleration, braking, steering);
- Communications;
- Modeling;
- Control and optimization of transportation systems.

The goal of these studies is to improve road transportation in terms of safety, efficiency, comfort and also to minimize nuisances.

- **Increase safety of road transportation** It is well known that road transport is not safe. This mode kills hundreds of thousands of people each year throughout the world and in particular young adults. Although safety has improved by one order of magnitude in the last decades through better infrastructure and safer cars, the limits of these improvements seems to have been reached if the travelling speeds remains constant (or are improved as is requested by the travelers). The techniques to improve drastically the safety are based on four approaches :
 - driver monitoring and warning;
 - partial control of the vehicle in emergency situations;
 - total control of some of the functions of the vehicle;
 - total control of all the vehicle.

The technical approach proposed by IMARA is based on drivers aids, going all the way to full driving automation. This is the core of the project's research effort and our goal is both to demonstrate technical feasibility by creating new concepts of vehicles and to bring new technologies on the road.

- **Minimize energy consumption** Drastic reductions in the consumption of fossil fuels is one of the challenges of the next twenty years. Objectives have already been set for the reduction of carbon dioxide in many countries. Road transportation plays now the dominant role in the consumption of these fuels and the trend is towards great increases through two factors : increase in freight transport by road and very large increase in car ownership in emerging countries. Without a radical departure from existing technologies and practices, the goals set by the states cannot be met. This goal is not directly a research topic but by promoting new systems of transportation with clean vehicles which can be optimized, IMARA contribute to minimize energy consumption.
- **Minimize pollutions and nuisances** In all large cities through the world, air quality is now monitored at frequently unacceptable levels. Noise levels in cities and near highways is the main complain by a large percentage of the population. Citizen are not yet ready to change their habits on a voluntary basis but they are now supporting legislation to curb car usage in cities. One of the objective of IMARA is to study new transportation modes and in particular to find ways to develop multimodality in order to find the most energy efficient way of satisfying transportation needs. In this respect, simulation and optimization of very complex transportation systems can give an insight of which solution should be deployed and where.
- **Offer a more pleasant living environment** Another nuisance often expressed by urbanites is the space taken by the automobile in cities which is responsible for many problems. The technical solutions to these problems of environment which are studied by IMARA are all based on a better

usage of the resources : space and energy. It is well known that mass transportation is most efficient in terms of space and energy but not very flexible and that the reverse is true for the private automobile. The solutions lies therefore in three directions:

- make a better use of existing infrastructures by minimizing congestion and increasing throughput,
 - use a multi-modal approach with the automobile at its proper place when the public transportation cannot offer a good service,
 - develop new public transportation modes close to the service offered by the automobile.
- **Offer new transportation means available to more people** Access to the automobile does not have to be exclusively through private ownership. This mode of access discourage strongly the use of alternative modes (such as public transportation or non-motorized modes) since the marginal cost of each trip is so low (unless penalized by parking cost or toll). New modes of access such as car-sharing, instant rental and self-service are now developed thanks to modern technologies. IMARA is strongly engaged in the development of such technologies as the team was involved in the Praxitele experiment.

The project provides to the different cooperating teams, some important means such as a fleet of a dozen of computer driven vehicles, various sensors and advanced computing facilities including simulation tool. An experimental system based on fully automated vehicles is now being installed on the INRIA grounds at Rocquencourt for visitors and employees.

3. Scientific Foundations

3.1. Introduction

Key words: *sensors, signal processing, control, communication, system, modeling, programming.*

3.2. Sensors and information processing

Key words: *sensors, signal processing, laser, radar, vision, image processing, magnetic devices, localization, obstacle detection, data fusion.*

3.2.1. Sensors and single-sensor information processing

The first step in the design of a control system are sensors and the information we want to extract from them, either for driver assistance or for fully automated guided vehicles. We put aside the internal sensors which are rather well integrated. Internal sensors give information on the host vehicle state, such as its velocity and steering angle information. The necessary information from external sensors (Laser, Radar, image sensors, etc.) are of several types:

- localization of the vehicle with respect to the infrastructure, i.e. lateral positioning on the road can be obtained by mean of vision (lane markings) or by mean of magnetic, optic or radar devices;
- localization of the surrounding vehicles and determination of their behavior can be obtained by a mix of vision, laser or radar;
- detection of obstacles other than vehicles: pedestrians, animals objects on the road etc. that require many types of sensors.

Since INRIA is very involved in image processing, IMARA emphasize the vision technique, particularly stereo-vision, in relation with MIT and ENSMP.

3.2.2. Multi-sensor data fusion

The next research problem is the multi-sensor data fusion system consisting of a set of internal and external sensors which information is fused within one data fusion unit. The different sensor processing units deliver processed information about the road geometry (curvature, etc.). They also deliver information about relevant objects detected in the vicinity of the vehicle. The fusion involves as its name implies the processing of various informations coming from different sensors in order to get a better picture of the environment of the vehicle. Two different sensors, apart from providing different coverage, can detect the same object, but with differing accuracy of the parameters (for instance, range and angle) describing that object. This information is complimentary, and leads to a measurement of higher integrity, accuracy and confidence. In addition to this, certain sensors may see information “invisible” to other sensors, such as video’s ability to locate road markings. This too assists in improving the positioning of objects with respect to the real-world, rather than the subject vehicle.

Since IMARA aims at integrating different techniques into real-world vehicles, it is implied into the development of data fusion work packages, i.e. in the CARSENSE project.

3.2.2.1. Associated projects:

Sharp, Icare, Fractales.

3.3. Control

Key words: *control, command, dynamic behavior, generating trajectories.*

The task is to develop a command system designed to execute at best the orders given by either the driver (aided by the system) or the automated driving system. The command system sends orders to the mechanical parts of the vehicles using all the information raised by the sensors. For example, one can imagine a steering system that acts not only on the wheels angle through the steering wheel but also on the brakes of each wheel. This would yield a much more secure behavior of the vehicle.

The real difficulty with this kind of control comes from the complexity of the dynamic behavior of the vehicle: response are highly non linear, particularly the response to forces of the tires on various soils. INRIA has a great expertise in these control problems and IMARA already demonstrated solutions for automatic driving of platoons of electrical cars. These research is still an active field. We want to enhance the system concerning the speed, the variety of wheel-soil contact. The lateral control problem is also studied, particularly in view of drivers assistance.

Another aspect of command systems is to generate correct trajectories which is another field of expertise for INRIA. These problems deal with obstacle avoidance or with generating complex trajectories in constraint environment (e.g. the parking problem).

3.3.1. Associated projects:

Sharp, Icare, Sosso.

3.4. System modeling and management

Key words: *system, modeling, simulation, management, infrastructure, multi-modality, information.*

The demand of transportation is a rapid growing sector. Even if some big cities try to limit the use of cars, there must be alternate transportation means, e.g. metro, taxi, bus etc. The challenge to the community and for the research is to propose plan for the long term and solution for the integration of the new techniques into the real world. Since the problem of transportation (and particularly of cars) is most acute in cities, this is the place where we concentrate our research effort. Of course some system could be then transposed into medium-sized cities or into the countryside.

In each of the following sections, there are 4 steps to achieve a good transportation system:

- measurement and analysis of the traffic.
- modeling of the transportation system;

- analysis of the model using mathematical analysis or through simulation;
- optimization of the required performance.

There are several fields where system modeling and management are applied.

3.4.1. Better use of existing infrastructure and vehicles

One of the great challenge of automobile industry and of cities administrations in the next years is to integrate cars in a saturated environment (traffic congestion, parking...). Research are currently done on regulation methods such as passage toll, car park toll, users information and multi-modality. This is a very topical theme as illustrated by London toll zone. This implies modeling the traffic in urban areas, modeling the behavior of drivers and measure by mathematical analysis or on simulations the results of various scenario and eventually optimizing parameters (toll, etc.).

Real time infrastructures management is also a problem of resources optimization but a dynamic one. The question is to control accesses to avoid saturation phenomena which could make fall the performances of the system. Studies should be led on real cases, such as for example a by-pass in Paris area.

3.4.2. Designing new infrastructure

With new infrastructures, the problem is to redesign the city transportation system and to measure the improvement linked to another kind of management. Since the space is very rare in central areas, deploying new infrastructures (e.g. tramway) often means replacing part of the existing infrastructures (e.g. roads). This can only properly done when the impact of the new infrastructure has been well designed, which means, as for the optimization of existing infrastructures, measuring, modeling and optimizing.

3.4.3. Increasing the transportation choice

With the automated road, problems to be treated relate primarily to the dimensioning of the infrastructures and the management of these infrastructures. Dimensioning can be approached by techniques of stochastic modeling at the microscopic level or more traditionally by techniques of operational research. IMARA already used successfully these techniques for the Praxitèle program and account to develop them within the framework of the automated road to provide tools which will make it possible to justify (or to invalidate) the investments.

3.4.3.1. Associated projects:

Preval, Metalau.

3.5. Communication

Key words: *Communication, LAN, Ethernet, radio, mobiles, dynamic routing.*

Communications will obviously play an essential part in ground transportation in a very near future and this is even truer for the automated road. Communications are indeed probably essential between close vehicles and between each vehicle and the infrastructure.

The traditional means of communication which are primarily in point-to-point mode or diffusion mode, do not seem adapted to the automated road. It seems that modes in hierarchical networks as for data processing would be better adapted to the problem. INRIA started to work on Ethernet type radio networks and with mobiles i.e. with a dynamic routing.

3.5.1. Associated projects:

Hipercom.

3.6. Tools for programming and certification

Key words: *Programming, certification, bugs, hardware, software, distributed environment.*

Data processing will play an essential part — even critical — for the safety of automated guided vehicles or even for simply secured vehicles. It is thus of primary importance to minimize hardware or software failures

and their consequences. For that, it became essential to bring new techniques of programming and certification. These work are already largely begun with INRIA and with the Ecole des Mines (Language ESTEREL and SynDEx) but the context of the automated road is even more critical than many applications than we try to approach. IMARA thus proposes to continue the development of its certification and programming tools ORCCAD and SynDEx in this automobile context i.e. in a very distributed — and thus necessarily redundant — environment.

3.6.1. *Associated projects:*
Sosso, Sharp, Icare

3.7. Ergonomics, Human-machine Interaction

Key words: *Ergonomics, Human-machine Interaction.*

Systems of driving assistance as well as automated driving devices go undoubtedly to change deeply interaction between drivers (or passengers if this one does not drive any more) and vehicles. As the concerned population will not be formed for that, it is imperative that interfaces be of a great simplicity and cannot be interpreted in an incorrect way. The safety of the system depends on it.

It will be particularly important to study the perverse effects of a diverted use of the considered systems and to include/understand the mental image of the system that users will build, including in its degraded modes.

3.7.1. *Associated projects:*
Eiffel

4. Application Domains

4.1. Introduction

If the preceding section stressed methodology, in connection with automated guided vehicles, it should be stressed that the evolution of the problems which we deal with remains often guided by the technological developments. We enumerate three fields of application, whose relative importance varies with time and who have strong mutual dependences: Driving assistance, cars available in self-service mode and fully automated vehicles (cybercars).

4.2. Driving assistance

Key words: *Driving assistance, information, modeling, path planning, system management.*

Several techniques will soon help drivers. One of the first immediate goal is to improve security by alerting the driver when some potentially dangerous or dangerous situations arise, i.e. collision warning systems or lane tracking could help a bus driver and surrounding vehicle drivers to more efficiently operate their vehicles. Human factors issues could be addressed to control the driver workload based on additional information processing requirements.

Another issue is to optimize individual journeys. This means developing software for calculating optimal (for the user or for the community) path. Nowadays, path planning software are based on a static of the traffic: efforts have to be done to put dynamic into softwares.

4.3. New transportation systems

Key words: *Transportation systems, self-service, on demand, information system.*

The problems related to the abusive use of the individual car in large cities led the populations and the political leaders to support the development of public transport. A request exists for a transport of people and goods which associates quality of service, environmental protection and access to the greatest number. Thus the tram

and the light subways of VAL type recently introduced into several cities in France conquered the populations, in spite of high capital costs.

However, these means of mass transportation are only possible on lines on which there is a keen demand. As soon as one moves away from these “lines of desire” or when one deviates from the rush hours, these modes become expensive and offer can thus only be limited in space and time.

To give a more flexible offer, it is necessary to plan more individual modes which approach the car such as we know. However, if one wants to profit from the advantages of the individual car without undergoing the disadvantages of them, it is necessary to try to answer several criteria:

- availability anywhere, anytime to all;
- lower air and soils pollution as well as sound levels;
- decrease the ground space occupied;
- secure;
- low cost;

Electric or gas vehicles available in self-service as in the Praxitèle system bring a first response to these criteria. To be able to still better meet the needs, it is however necessary to re-examine the design of the vehicles on the following points:

- ease empty car moves to better distribute them;
- better use of information systems inboard and on ground;
- better integrate this system in the global transportation system.

These systems are now operating (i.e. in La Rochelle). The challenge is to bring them to an industrial phase by transferring technologies to these still experimental projects.

4.4. Cybercars

Key words: *Cybercars, B2.*

The long term effort of the project is to put automatically guided vehicles (cybercars) on the road. It seems too early to mix cybercars and traditional vehicles, but data processing and automation now make it possible to consider in the relatively short term the development of such vehicles and the adapted infrastructures. IMARA aims at using these technologies on experimental platforms (vehicles and infrastructures) to accelerate the technology transfer and to innovate in this field.

IMARA is also developing a new prototype vehicle, the B2. Originally conceived within the CyberCars Project, the intended goal of the B2 is to provide an on-demand, fully automatic taxi service in an urban environment. It represents our goals of an extremely compact and maneuverable machine. At the same time, the B2 is also mechanically simple which reduces manufacturing cost while also minimizing operating costs. Even so, it is a vehicle capable of carrying two people and reaching speeds of 30km/hr; It can turn on itself by virtue of its differential motors; and it is capable of completely automatic control, and thus a true Cybercar.

Other application can be precision docking systems that will allow buses to be automatically maneuvered into a loading zone or maintenance area, allowing easier access for passengers, or more efficient maintenance operations. Transit operating costs will also be reduced through decreased maintenance costs and less damage to the breaking and steering systems.

7. Contracts and Grants with Industry

7.1. Introduction

The IMARA project is mainly funded by the numerous contracts obtained the past years and which show the guidelines of its works.

7.2. STARDUST

Stardust is a research project supported by the European Commission under the Fifth Framework Programme and contributing to the implementation of the Key Action "City of Tomorrow and Cultural Heritage" within the Energy, Environment and Sustainable Development

The objective of Stardust project is to assess the extent to which ADAS (Advanced Driver Assistance Systems) and AVG (Automated Vehicle Guidance) systems can contribute to a sustainable urban development not only in terms of direct impacts on traffic conditions and environment but also in terms of impacts on social life, economic viability, safety, etc.

Contractor: EU-IST

Project duration: 4 years (2001–2005)

Web site: <http://www.trg.soton.ac.uk/stardust/>

7.3. ARCOS

ARCOS means "Action de Recherche pour une CONduite Sécurisée", i.e. "Research Action for Secure Driving".

ARCOS is a pre-competitive research project. It takes place into the PREDIT program. This project aims at improving road safety, with a global goal of 30% accidents reduction. ARCOS considers vehicle, driver and road as a whole system. Thus, the project aims at enhancing driving safety on the basis of four safety functions :

1. controlling inter-vehicle distances;
2. avoiding collisions with fixed or slowly moving obstacles;
3. avoiding lane exit;
4. alerting other vehicles of accidents.

ARCOS' originality comes from the management of technical specifications through these functions. This is the heart of the project. ARCOS is managed like industrial projects. It comprises eleven research themes, which integrate engineering, human and social sciences.

These emergency management modes enable us to identify the three project deliveries:

- alerting the driver: information means, no action;
- marginal automatic action in a man-machine cooperative mode: interactive means, cooperative actions;
- emergency automatic action : active means, delegate actions.

Contractor: MEFI & ARMINES

Project duration: 3 years (2002–2005)

R& D investment: euros 13 millions;

58 research partners (public laboratories and industrials).

7.4. Cybercar

The objective of the project CyberCar is to bring all the European actors of this field together in order to test and exchange best practices, share some of the development work and progress faster in the experiments. Several cities throughout Europe have already accepted to participate in the project and will study with the partners of the project the potentiality to run such systems and give their specific constraints. A major part of the work carried during the project, will be the development and test of several key technologies for the enhancement of the existing systems. These technologies concern better guidance, better collision avoidance, better energy management, better fleet management and the development of simple and standard user interfaces. Cooperative work is also needed at the European level in order to reach a consensus on the certification techniques of these systems which are now developed in a very imprecise regulatory framework.

Contractor: CEE-IST

Project duration: 4 years (2001-2005)

R&D investment: euros 798 000.

7.5. Cybermove

The goals of the CyberMove project are to improve the attractiveness and quality of life in Anyville by reducing the use and the parking needs of traditional cars. This will be achieved by new transportation systems based on cybercars as a complement to public mass transportation. Cybercars offer a cleaner and safer transportation mode available to everyone including people who cannot (or should not) drive for a level of service better than with private cars (door to door, individual, on-demand transportation).

CyberMove's aim is to create a new transportation option for city authorities to move towards sustainability and increase the attractiveness of city centres.

Contractor: CEE-IST

Project duration: 4 years (2001-2005)

R&D investment: euros 319 000.

7.6. CARSENSE

A consortium of 12 european car manufacturers, suppliers and research institutes has found 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 article shall describe the main targets of the programme linked to the improvement of the individual sensors and in the merger of the information in a fusion box

Contractor: CEE-IST

Project duration: 4 years (2000-2004)

R&D investment: euros 244 000.

7.7. Ozone

The OZONE project will investigate, define and implement/integrate a generic framework to enable consumer oriented ambient intelligence applications.

Contractor: EU-IST

Project duration: 32 months (2001-2004)

R&D investment: euros 173 000.

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