Total road safety: let us remove the driver from the control loop

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Abstract— Automobile has become the dominant transport mode in the world in the last century. In order to meet a continuously growing demand for transport, one solution is to change the control approach for vehicle to full driving automation, which removes the driver from the control loop to improve efficiency and reduce accidents. Recent work shows that there are several realistic paths towards this deployment : driving assistance on passenger cars, automated commercial vehicles on dedicated infrastructures, and new forms of urban transport (car-sharing and cybercars). Cybercars have already been put into operation in Europe, and it seems that this approach could lead the way towards full automation on most urban, and later interurban infrastructures. The European projects CyberCars and CyberMove are exploring the technical and the socio-economic feasibility of this approach.

***Keywords*— Automated driving, automated vehicles, cybercars, Urban transport, intelligent transportation systems (ITS).**

INTRODUCTION

Throughout the twentieth century, the automobile and its infrastructure were developed in such a way as to become the dominant transport mode for passengers as well as goods in most countries. Although this quantitative development has not reached its full extent in many countries (with enormous potential for growth in Asia), in most industrialised countries a saturation point seems to have been reached (or is being approached) in terms of infrastructure as well as number of vehicles.

In cities, the automobile is very inefficient in terms of space usage, in particular in its private form (where it stands still for most of the time) and can be responsible for a decrease in urban mobility in the densest parts which see a reduction of visitors. The car manufacturers are now introducing new technologies in their vehicles in order to respond to these inefficiencies. These technologies, which belong to the ITS (Intelligent Transportation System), domain, are based on driver assistance of different kinds such as navigation and route guidance, automatic distance keeping, obstacle avoidance, lane keeping, parking assistance, and so on. The objectives of these new functions are to improve comfort for the driver and also to improve safety. It has been shown (see the European Project Stardust at www.trg.soton.ac.uk/stardust/) that these functions can also improve, in some cases, the throughput.

However, in order to meet a continuously growing demand for transport while improving the safety, the only solution seems to be to remove the driver from the control loop and to manage the transportation system in a more coordinated way.

Indeed, in cities where most of the problems of transportation are concentrated, the solution for better transport for all, lies certainly in less cars (as we know them today), better public mass transport and in a new

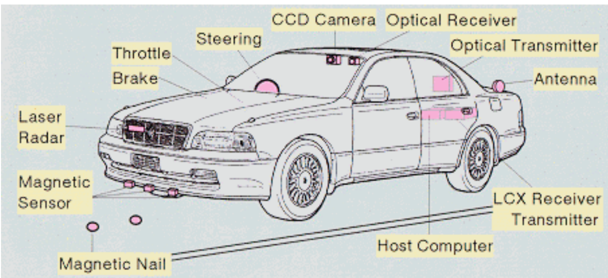

Fig. 1 Drivers aids

form of cars which we call cybercars. Cybercars are fully automated road vehicles dedicated to the city, for passengers or for goods, with fully automatic driving capabilities. These cybercars, which are part of the public transportation system (at least at the beginning of their introduction), can complement in a most efficient way mass transport and soft modes (walking, cycling,….) in order to improve mobility while at the same time improving the quality of life and maintaining sustainability.

Cybercars started to appear at the end of the 1990's in Europe in different places as automatic people movers in

Fig. 2 : First cybercar in operation at Schiphol airport (1997)

airports or other private locations. It has been demonstrated (see www.cybermove.org) that this technology, still at its infancy, can bring an efficient solution to some transportation problems over distances up to a few kilometres. However, through the development of the technologies, in the next decade, cybercars could offer a key solution to urban mobility.

This article will present the technologies used in the cybercars today, their development throughout the CyberCars Project financed by the European Commission (www.cybercars.org) and the potential for future developments.

I. Control Technologies

Cybercars by definition are under full control of computers and/or microcontrollers. These controls have to operate in particular on the three elements of a vehicle for its motion: acceleration, deceleration (and stopping) and finally steering. These controls are well known in the field of industrial robotics; however, up to now their installation on a road vehicle running in an external and less controlled path has been far from easy.

In fact the first computer controlled vehicles, derived from existing robotic solutions, were not well fitted to this more difficult environment, often with poor control performances and especially poor reliability. Now, thanks to recent advances in drive-by-wire technologies from the automotive sector, the control of fully automatic vehicles becomes a bit easier, in particular with the availability of hardware components such as computer controlled actuators for braking or steering.However, the design, development and validation of such computer controlled systems is far from easy and, for a low volume production, the cost can be high and the reliability not certain.

The focus of the work on controls in CyberCars was therefore to develop new hardware products as well as software production and validation technologies, to simplify the development phase.

The following aspects characterise this approach:
- **Improved integration** for different functions (traction, braking, steering) under full computer control;
- **Reliability**, especially for safety critical controls;
- **Distributed system approach**, allowing a flexibility of implementation for the different applications;
- **Methods for easy design** and validation.

At the end of the project, it can be said that consistent improvements in distributed and safe architectures, as well as the HW subsystems have been reached. SW packages, in part already existing, have been improved and tested on various platforms. Moreover, a solution for a longer term application of cybercars has been investigated, addressing the architecture of a dual mode vehicle which can be manually driven on ordinary roads and automatically controlled in a more dedicated infrastructure.

The main results in the area of vehicle controls, are therefore as follows:

- The development and application of the **software tool** SynDEx, for optimising distributed real-time embedded systems (INRIA - paragraph 3.2); the SW has been used by project partners for several applications; to create, implement and certify the control systems; rapid prototyping has been demonstrated.
- Advanced **architecture and components** for the second version of the Park Shuttle, with double CAN network for improved reliability : in particular the system provides redundancy for safety critical applications and three different levels of braking (normal, fast and emergency);
- **A CAN based architecture** implemented in RobuCar, CyCab and Yamaha vehicles (INRIA) and in the test platform prototype (ISR);
- **A new braking system** offering improved comfort (low jerk) and enhanced vehicle range by energy regeneration (YME – see paragraph 3.4); the system has been tested at the Floriade show on 25 vehicles running for 5000 Km each.

II. Navigation technologies

Up to now, the few existing cyber cars are non-flexible vehicles, based on proprietary navigation systems which are developed for very focused applications, like People Movers.

In the existing applications, several techniques for localisation and navigation are employed, like wire guidance, transponders, magnetic sensors, and GPS. All of these have some advantages but also some drawbacks, as summarised in the following table.

In particular, wire guidance and transponders still present problems especially with installation procedures, maintenance and cost. The GPS system appears as a very flexible approach (considering the differential and real time kinematics methods, which offer suitable accuracy), but could present difficulties in a city area with the satellites can be obscured. The inertial sensors and micro-gyros can be installed on cars, providing an interesting measurement technique, which however should be integrated with other techniques (like odometer data and or GPS), since accuracy is not sufficient at the present stage.

Such a situation suggested to concentrate efforts regarding navigation technologies on the following points:

- Improvement of some known and simple solutions, particularly the **magnetic localisation**, in term of cost, accuracy and easy installation on board;
- Study of solutions allowing a **limited investment in the infrastructure:** emphasis has been given on autonomous vision or laser systems based on landmarks;
- Effort to implement a modular architecture, allowing the **flexible adaptation** of different techniques on vehicle platforms, depending on application requirements;

A standard on-board computer, a localisation and guiding system, and an anti-collision system, constitute the key subsystems for such a modular approach; their features will depend on the characteristics of the application, such as the environment, the vehicle speed, the network structure. In this way, it is possible to customise the design and the integration process for new vehicles and for specific uses. This approach may also contribute to specify standardized interfaces (hardware and software) for cybercars.

The results of these activities are a significant improvement of two vehicle platforms (ParkShuttle and Robucab) and the availability of several research prototypes ready for extended testing.

Going to more technical details, the following major results can be highlighted:

-The **magnetic ruler technique** on the ParkShuttle has been improved with new signal processing schemes: this resulted in halving the density of sensors, increasing the distance from the antenna to the magnets (20 cm), and obtained better accuracy of 0,1 m at 20 Km/h;
- In another configuration (Ruf vehicle and elevated rail infrastructure) a **magnetic probe** based on induction has been studied and realised; the very compact device is able to control the path of a collective Cyber car when choosing among different tracks .
- A **vision system** on the CyCab platform allows to reconstruct the left and right borders of the road, being well adapted to capture the dynamic features of the scene; it has been tested in urban areas (city centre and harbour of Antibes) at 36 km/h and 25 frames per second;
- A **modular architecture** has been implemented in different platform; a particular example is the RobuCab, where different composition of modules allows to implement various applications such as vehicles for public or for individual urban transport, teleoperated vehicles, outdoor platforms for research.

Other additional results concern the setting–up and evaluation of some more traditional techniques, like the wire guidance and the scan laser with reflecting beacons. Regarding autonomous techniques, other prototype systems have been realised and tested in this project, like a vision system able to track a painted line, which for the moment operates at low speed (paragraph 4.7), and a GPS receiver coupled with inertial sensors

All these activities have confirmed the basic role of navigation technologies for the correct operation of Cyber cars.

In particular, the improved magnetic rulers are considered a fundamental option for short term applications on local tracks, with a combination of straight parts and curves. In a longer time perspective, computer vision could offer interesting possibilities with a lower impact on the infrastructure. Inertial sensors are a relevant technology to follow for future developments, even if they do not provide today the necessary performance; however improved characteristics and lower costs are anticipated, due to the on-going trends of Microsystems technologies for automotive products.

III. OBSTACLE DETECTION TECHNOLOGIES

One of the most challenging problems of CyberCars is safety on the roads, in particular the avoidance of obstacles while preserving a reasonable commercial speed. This is a basic requirement for the evolution of cybercars, according to the evolutionary roadmap. In fact, even in the first steps, when vehicles are operated on a dedicated lane with some type of barriers, the presence of somebody crossing the path or the interaction with an obstacle cannot be excluded.

The existing technologies for safety rely on expensive laser systems, typically with a scanned beam, detecting objects in the front area and on tactile bumpers, switching off the traction in case of a contact.

Regarding vision systems, a certain experience on road vehicles already exists, but consolidated applications are based on simple processing tasks (not directly related, on present products, to obstacle detection): an example is the recognition of white marks on the road for lane keeping. In robotics, most of the systems are based on stereo cameras and an inverse perspective mapping, with the assumption of a flat road. These solutions operate correctly only when calibration and installation are accurate, and also when the assumption of road flatness is not significantly violated.

In this context, besides trying to reduce the cost of a laser system, it is important to develop new detection technologies offering additional flexibility, more precise information on the environment, and simplified procedures. In the area of computer vision, the work has been concentrated on stereo systems, with solutions offering simplified calibration and avoiding the assumption of a flat road.

Therefore, the following approaches have been considered:

- **Techniques to improve safety** for both road users and cybercars users, in several operational conditions, mostly based on improved processing of laser signals;
- Improvement of **image processing for stereo vision**, focusing on the modelling of the environment, the calibration methods and the path tracking;
- The evaluation of **automotive radar systems** (devices, processing), which could provide a low cost and reliable solution due to the high volume productions;
- The testing of well known **ultrasound sensors**, offering an economic device with however some environmental limitations.

The results obtained in the CyberCars project are here summarized:

- **Automotive radar sensors** and systems have been evaluated in two configurations by CRF; suitable performances have been demonstrated in a platooning scenario and when braking behind a stopped vehicle; the angular field of view now offered has been found insufficient;
- Some advanced solutions for **stereo vision** have been implemented, including:
  . a technique with simplified calibration and applicability on non-flat roads
  . a technique based on 3D models with an 'evolutionary' approach allowing pattern recognition
  . new data processing has been developed for a **dual laser scanner** on the Park Shuttle, with measurements performed at two heights for increased safety; the system provides a recognition of on-path and near-path obstacles, an easy and automatic configuration of the area of interest from the route plan, and enhanced comfort due to strategies for a gradual stopping;
  . other more **standard solutions** have been tested for the purpose of understanding the domain of operation, particularly a certified laser scanner and a device with low cost ultrasonic sensors;

From the experience gained in the work, it can be concluded that the scan laser remains at the moment the preferred option, with significant improvements now obtained in the data processing. For this technology, it is now known that suppliers are developing second generation devices for application on vehicles, with smaller dimensions and a reduced cost.

The automotive radar has shown an interesting potential for cybercars, when systems with a larger field of view will be available, as expected from the present trends.

Finally, vision systems maintain a great interest for the variety of functionalities they provide, also considering the integration of obstacle detection and navigation. In this area, significant progress has been obtained, but further experimentation and setting-up appears necessary for cybercars.

IV- PLATOONING TECHNOLOGIES

Platooning techniques are needed for cyber cars for two different reasons :
- for offering the possibility to move empty vehicles from one location to another one, using a single driver;
- for increasing the throughput of cyber cars on a given infrastructure, by reducing the headway to a strict minimum.

In both cases, the following vehicles should follow the preceding vehicles as close as possible, on the same tracks and without collision, even in case of hard accelerations and decelerations.

Only a limited experience is available on this topic.
A certain similarity exists with present-day commercial techniques, used in Adaptive Cruise Control (ACC) for automobiles, which are based on ranging systems, such as lasers or radars, and concern only the longitudinal guidance.

New improvements are under way at research level, which consider longitudinal and lateral guidance using vision and targets (Chauffeur Project from the EC and ICVS system from Honda) or radar and markers on the road (IMTS from Toyota). INRIA has patented a platooning technique with a more advanced vision sensor, which does not require a communication link between the vehicles, nor markers on the infrastructure.

Based on the above picture, the project activities on platooning have been focused on the sensor issues, taking into account the coupling of longitudinal and lateral guidance, and aiming to avoid the use of equipment in the infrastructure.

Three techniques have been addressed, and demonstrated in simple scenarios in a test area.

The first approach uses a **camera based technique extracting features** from the image of the preceding vehicle : the method proved to be a basic building block for a fleet of homogeneous vehicles, which is adaptable to different vehicles by simple SW modifications;

The second approach applies a **laser scanner with reflective beacons**. This is a simple method which could provide distance and orientation of the preceding vehicle between 2 and 15 m; it has the advantage of adding practically no cost if the same laser sensor is used for collision avoidance.

The third approach is a **camera based technique with IR lights** according to the patent previously mentioned. Progress has been made in the use of low cost vision sensors and the coupling between image processing and control.

From the above developments, a **preliminary feasibility of platooning schemes at low speeds has been demonstrated** and the **approaches for possible applications** have been identified.

Additional work remains to be done to consolidate these techniques and to define details of the solutions for a demonstration site. A specific challenge to be addressed in future work concerns the issue of string stability and the robust control for such a train of vehicles.

V- CONCLUSIONS

Cybercars are still at their infancy but they show great promises. In the short time period of the CyberCars project (2001-2004), significant technical progresses have been achieved. These technical improvements are now being continued in the CyberCars-2 Project. These new techniques will be demonstrated in the large scale project CityMobil, also financed by the European Commission, where cybercars will be put in place at several locations in Europe.

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ParkShuttle II

ULTra cybercars

CyCab