The automobile played a major part in the 20th-century development of urban (now mostly suburban) organization and became fundamental to its operation. We must now think about a new form of urban transport to meet the 21st century’s challenges. In Europe, several programs are looking at technologies based on automated transport over existing and possibly new road infrastructures. These transport systems require a hierarchical network with very-high-capacity links, along with medium- and low-capacity links, optimization, and demand control. The objective is to provide door-to-door transport to anyone (or anything) at any time but at different costs, depending on the modes used.

CyberCars (www.cybercars.org) is one of several European projects that have begun developing these technologies. Now, in accordance with several European Commission recommendations,1,2 the CityMobil project (www.citymobil-project.eu) is implementing them.

Cybernetic transport

Cybercars are fully automated road vehicles. A fleet of such vehicles forms a cybernetic transportation system for passengers or goods, operating on either a simple route or an elaborate network to provide on-demand door-to-door transportation. The CTS controls the fleet through a central management system, distributing transportation requests efficiently and coordinating traffic in a particular environment. Initially, cybercars will support short, low-speed trips in an urban environment or on private property such as a university campus, resort, or industrial site. In the long term, cybercars could also run autonomously at high speeds on dedicated, protected tracks. Cybercars can complement mass transport either in time (when mass transport isn’t running efficiently) or in space (to do the “last mile”).

The first cybercar system went into operation in December 1997 at Schiphol airport with a fleet of four automated electric vans that ran fully autonomously on a demand basis. The next big step will be in 2008 when a more ambitious system starts operations at London’s Heathrow airport (see figure 1). In between, a system has been running since 1998 in a Rotterdam suburb, linking a train station and an office complex.

Control

Cybercars are precursors of drive-by-wire vehicles. Computers control the acceleration, braking, and steering. Project participants have already developed new hardware for implementing these functions safely. However, the development has focused mainly on safe software in standard architectures with little parallelism. Future control systems must rely on redundant systems to reach the safety levels required in the complex, often distributed CTS computer environment.

Software development for such systems is still difficult, as is system certification. INRIA has developed Syndex (www-rocinria.fr/syndex), a tool to support these tasks for distributed real-time software. Syndex is based on a development approach that lets developers dissociate the writing of the application software from the distributed hardware architecture. Syndex then distributes the final software, with all its communications needs, into the various vehicle controllers.

Some of Inria’s partners have used Syndex extensively and validated it for advanced urban transport system development.

Obstacle avoidance

Obstacle avoidance is the main difficulty in cybercar deployment, particularly when the cars run in unprotected environments—that is, environments with pedestrians, cyclists, or even other vehicles. The CyberCars project partners have performed considerable research in this domain.3 Commercial vehicles now come with obstacle-avoidance systems based on scanning-laser range finders complemented by ultrasound and sensing bumpers. These sensors are integrated with advanced control software to avoid collisions while ignoring obstacles that aren’t on the vehicle paths.

Other research on collision-avoidance techniques focuses on radar and vision. These aren’t yet certified but
promise to lower costs and improve performance. This research involves close cooperation with the automobile industry, which is looking to apply collision-avoidance technologies in current vehicles. For vision, the trend is to use hierarchical methods that handle the massive number of low-level operations in hardware and send higher-level objects to various routines. For example, this approach can implement genetic algorithms, such as the Fly Algorithm, in hardware to quickly capture hints of pedestrians in the vehicle path; then it uses that information to launch refined, computer-demanding methods in these local areas of the images.

**Platoon operation**

Platooning techniques manage the operation of several closely spaced vehicles. The first vehicle of a platoon might or might not be automatic, depending on the application. The CyberCars project has developed two techniques. One relies on the scanning laser sensor used for obstacle avoidance; the other uses a linear camera developed with low-cost components. Both approaches give good results, but the linear camera could support a very small distance between vehicles and high-speed operation.

Next-generation platoons will use intravehicle communication to solve problems such as adding a car to the platoon, splitting the platoon, or managing what happens when two platoons meet at an intersection. This communications capability will also help stabilize platoons to avoid collisions during maneuvers such as stop and go.

**Localization and navigation**

The first automated vehicles used an infrastructure-based approach to path control, which depended on electric wires or transponders. During the CyberCars project, Frog Navigation Systems (www.frog.nl) developed a technique based on dead-reckoning associated with relocalization on widely spaced magnets. Implementing this technique is relatively inexpensive, and it lets the system operator fine-tune the vehicle paths. It’s available on the Netherlands’ ParkShuttle II people-mover system (http://connectedcities.eu/guide/parkshuttle.html), where it requires fewer magnets on the road than earlier systems that used pure servoing on a string of magnets.

Researchers in the robotics community have demonstrated other localization-based navigation techniques using lasers, natural environmental features, or vision systems. These techniques require no modification of the environment but aren’t yet industrialized. Researchers are also having some success exploring advanced techniques for path generation in complex, dynamic environments.

A low-cost solution in development uses the same architecture as the obstacle detection for localization, but it extracts map features at a high level, drastically reducing the amount of data the GIS must store. Then it computes a 2D path that accounts for obstacles seen or transmitted by the surrounding sensors. Nearby cybercars share their information to enhance the range and precision of environmental sensing.

**Fleet management**

The industrial companies involved in the CyberCars projects have developed management software based on a centralized system and communications. These systems offer flexible operation. They can implement demand-responsive transportation for a few vehicles, with minimum waiting times.

At the research level, new techniques are in development to optimize large-scale systems. For example, hierarchical control ensures good redistribution of cybercars at the fleet level so that supply and demand coincide. At the local level, an intersection-control system manages incoming cybercars to optimize throughput and safety. At the cybercar level, onboard control deals with the trajectory and obstacle avoidance.

**Communications**

Good communications between the vehicles and the infrastructure and between the infrastructure and the users are essential for any good transportation system. In the case of cybercars, where the vehicles run according to demand, it’s even more essential. The project has used various communication schemes that are now operational on various systems: GSM and GPRS for communicating with users through their mobile phones and Wi-Fi (IEEE 802.11) for the communication between vehicles and infrastructure. High-bandwidth communication is required for applications involving image transfer, such as vehicle remote control.

The CyberCars-2 project (www-c.inria.fr:9098/cybercars2) is now experimenting with mobile ad hoc networks that account for cybercar mobility in particular—for example, networks that use adapted versions of the Optimized Link State Routing protocol (www.ietf.org/rfc/rfc3626.txt). These networks are well suited to cybercar systems because they always offer sufficient density. The next steps are to demonstrate them in large systems and to address the handover between different communication technologies, such as 2G, 3G, Wi-Fi, and satellite.

The technologies to support automated road vehicles are already well developed, and some are operating in real-life applications. But this is only the beginning. Thanks to projects like CityMobil, the European Commission expects cities to become more
interested in how these vehicles can improve mobility while reducing current automobiles’ negative impact.

However, safety and reliability remain major issues for these new systems. Traditional vehicles on public roads must meet many requirements stipulated in standards and regulations. For new systems like CTS, such standards don’t yet exist, and the existing standards for other road vehicles aren’t always suitable. CTS success depends on further progress in automated-vehicle technologies and their certification.

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References


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