# AUTOPIA Program Advances: How to Automate the Traffic?

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**Abstract.** Road transport fatalities are one of the major causes of death in developed countries, so the investigation in aid systems for vehicles to reduce these figures is nowadays an open field of research. With this final goal, AUTOPIA program has been working from 1996 in the development of aid driving systems and, specifically, in autonomous systems capable of replacing the driver in some specific tasks, reducing so, the dependence on the human driver. In this paper we present some of the most relevant advances achieved using commercial vehicles. To achieve this objective, prototype vehicles have been equipped with capabilities to permit it to act over the actuators of the vehicle autonomously. Several cooperative maneuvers have been developed during last years toward a final goal: an intelligent traffic control system.

## 1 Introduction

The use of road networks as main transportation system causes a saturation in the vicinity of large cities. One way to try to solve this problem is based on the development of *Advanced Driver Assistance Systems* (ADAS) to relegate the drivers from some tedious driving-related tasks to make the driving easier and safer. The AUTOPIA program is focused in this line. In this connection, this paper presents the more significant advances achieved by the group in recent years toward a traffic control system on a prototype commercial car that can be easily translated to the market.

A brief summary about the main results in the ADAS field can start in the late 1950s and 1960s when speed controllers with errors up to 16 km/h were available [17]. Nowadays, *Cruise Control* (CC) systems, and its improvement to *Adaptive CC* (ACC) systems, are capable of working at speeds greater than 30 km/h either to follow a reference speed or a leading vehicle respectively. However, this systems are not available for urban traffic where the congestion is greater.

* This work was supported by the Plan Nacional, under the project Tránsito (TRA2008-06602-C03-01) and by the Comisión Interministerial de Ciencia y Tecnología under the project GUIADE (Ministerio de Fomento T9/08).

R. Moreno-Díaz et al. (Eds.): EUROCAST 2011, Part II, LNCS 6928, pp. 374–381, 2012.

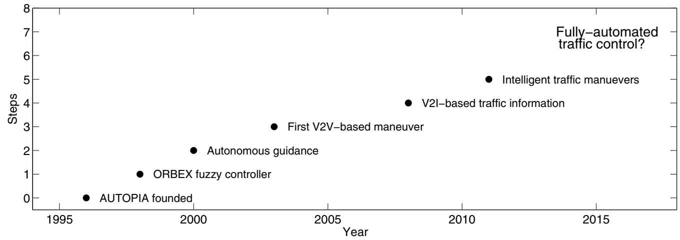


**Fig. 1.** AUTOPIA program advances toward a fully-automation traffic control system

Indeed, commercial systems only take into account the leading vehicle but most of traffic collisions occur at crossroads and vehicle driving in perpendicular road have to be considered.

This communication presents AUTOPIA approach to attack several of these yet unsolved topics in the automotive sector. ADAS advances, in our opinion, will cause the coexistence of vehicles that can be guided through automatic controllers and vehicles driven manually in a large-medium term. So, to validate the proposed controllers, a gas-propelled convertible Citroën C3 Pluriel has been equipped with automatic driving capabilities and another Citroën C3 is endowed with the needed equipment to be capable of sending relevant data between vehicles. The former has the throttle and brake actuators fully-automated and the latter is manually driven. Different fuzzy-logic-based controllers have been developed to deal with all these maneuvers.

## 2 AUTOPIA Program

Last decades have seen significant advances in the driver aid systems' field [18]. First results were obtained using on-board sensor systems – lidar, radar, ultrasounds or cameras – to advise the driver in case of a risk situation using a human-machine interface (HMI) [1]. Next steps were focused on the development of systems capable of aiding the driver in specific driving-related tasks – cruise control (CC), lane keeping assistance (LKA) or intelligent speed assistance (ISA). Nowadays, active systems to prevent or mitigate collisions – emergency braking (EB) or collision avoidance (CA) – are being implemented in commercial vehicles. All these advances bear in mind as a long-term goal autonomous vehicles driving along the roads and, consequently, a fully-automated traffic control.

This paper presents the AUTOPIA program advances toward an automated traffic control system (see figure 1). AUTOPIA has been working in the development of intelligent transportation systems (ITS) during the last 15 years. In this time, it has designed, developed and implemented two fully-automated electric Citroën Berlingo vans [15] and a fully-automated convertible Citroën C3 Pluriel [7]. Nowadays, the automation process of a Citroën C3 and a electric minibus are in progress. These vehicles allow us to perform not only autonomous guidance but also cooperative maneuvers involving two or more than two vehicles.

### 2.1 First Steps

AUTOPIA is a program whose long term goal is the automation of vehicles. This is not, of course a short term realistic goal, but many of the developments necessary for the automatic driving can be implemented as driver warning systems

The AUTOPIA program arose at the confluence of two trends, one of them, fuzzy systems the other mobile robots. The group had been working these subjects for several years when they realized that automobiles where essentially mobile robots and much cheaper. They also realized that the fuzzy control techniques they had been using could perfectly be used to control the automobiles. So, the AUTOPIA program started in 1996.

The group had been working for a long time in fuzzy sets, doing projects such as the control of a special robot to tune Ultra High Frequency (UHF) amplifiers [4], a task that took a human operator about one hour and less than a minute to the robot. They also had cooperated with projects whose aim was to develop a fuzzy chip [2]. Part of these efforts consisted in the development of the ORBEX, a software system that permitted define the fuzzy control in terms of *IF ... THEN ...* sentences very similar to natural language [3].

From the very beginning the goal of the program was to perform real tests with real cars. So, the project started building a test track consisting of about 1km of roads organized to simulate three blocks of a city, the longest path being 250m long. Then the master sensor was decided it should be a real time *Kinematic-Differential Global Positioning System* (RTK-DGPS). This was not a cheap decision, but this one sensor permitted to acquire full knowledge of the position and the development of the algorithms, that would work equally well if the information was acquired by other means.

The first experiments were done on electric vans [13], but it was soon found out that there was no great difference with gasoline cars. In any case, the vehicles were equipped with WiFi and a RTK-DGPS. WiFi was used to feed the RTK corrections to the vehicles, so the GPS could achieve the centimetric precision. The equipment of the vehicle included a computer and a motor card.

### 2.2 Recent Years

Next step in our research was focused in the development of cooperation between two vehicles. The first implemented maneuver was and adaptive CC (ACC) [12]. To this end, the radio system was replaced by a wireless communication system that was used both to receive the differential correction and to send information between the vehicles.

Later, information coming from the infrastructure was introduced in our control system – using mainly radio frequency identification (RFID) and Zigbee technologies. This was motivated by the fact that present vehicles are not equipped with vehicle to vehicle communication ability and vehicle to infrastructure communication is needed to send information about its position, direction and intention without modifying the present vehicles. First tests with these technologies were done in 2008 [10] and 2009 [16] with encouraging results.

**Fig. 2.** AUTOPIA program cars. A fully-automated convertible Citroën C3 and and intelligent Citroën C3 car.

We are now working toward a new architecture [5] capable of integrating all these advances to perform an automated traffic control system. Bearing this in mind, a control station to manage a local area of traffic has been introduced and will be in charge of managing all the information coming either from the vehicles or the infrastructure with the goal of reducing the traffic accidents.

## 3 Vehicles

Two gas-propelled vehicles are used in the experimental phase (see Fig. 2). The former is a convertible Citroën C3 Pluriel with throttle and brake pedals modified to allow automatic driving with an on-board control unit (OCU) equipped with ORBEX. The latter – used to perform the cooperative maneuvers – is a Citroën C3 equipped with sensory information to permit exchange data about its position and speed with the autonomous car. This section describes the Pluriel's automation process and the vehicle's equipment.

### 3.1 Autonomous Vehicles

The Pluriel car is fully automated, i.e. the throttle and the brake are fully computer controlled [7]. As positioning sensors, the vehicle has an RTK-DGPS and an inertial measurement unit [8] connected to the OCU, capable of providing positions at a $5Hz$ rate. Data such as speed or steering wheel angle are obtained reading the vehicle's CAN bus.

The control signal of the throttle is an electric value. In the Pluriel's case, the action over the pedal is emulated using a signals computer laboratory card. The braking system was designed with the sole premise of maintaining the original car circuit operation all the time. For this reason, a selector valve was installed that allowed to merge the original braking system with the one we installed. The pressure generated is proportional to an analog signal. In case of need, the operator in the vehicle can step on the brake pedal and, should this pressure be greater than the computer generated one, the selector card would yield and the brake-by-wire would be activated [6].

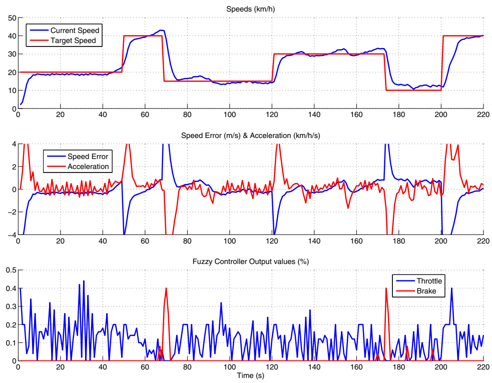


**Fig. 3.** Speed control experiment

### 3.2 Intelligent Vehicles

AUTOPIA has another type of vehicle, which can be named *intelligent* as it is carries electronic instrumentation although it is not automated. The goal of this vehicle is to cooperate with the automatic vehicle, although it is manually driven. The intelligent vehicle carries a computer, and a RTK-DGPS which is used to obtain both position and speed. This car is not modified so it can freely circulate along the roads. The communications system is identical to that of the automatic vehicle. This vehicle cooperates with the automatic one in maneuvers such as adaptive speed control or traversing crossroads.

## 4 Some Experimental Results

This section presents some of the achieved results during last years. Specifically, a speed control system at urban speeds, an ACC maneuver involving two vehicle and an intelligent intersection are described.

### 4.1 Speed Control

Figure 3 presents a trial with our convertible Citroën C3 performing a speed control experiment. The upper plot shows the current – blue line – and target – red line – speeds. The middle plot shows the values of the fuzzy input variables – Speed Error is plotted in blue line and Acceleration is plotted in red line – and, the lower plot depicts the output of the fuzzy controller, that is, the action over the throttle – blue line – and brake – red line – pedals generated by ORBEX (see [14] for more details about the controller).

One can appreciate how the fuzzy speed control is capable of following the target speed with good accuracy. Note that the obtained results are encouraging in spite of the apparently low control cycle rate – set at $5Hz$ by the on-board GPS receiver.

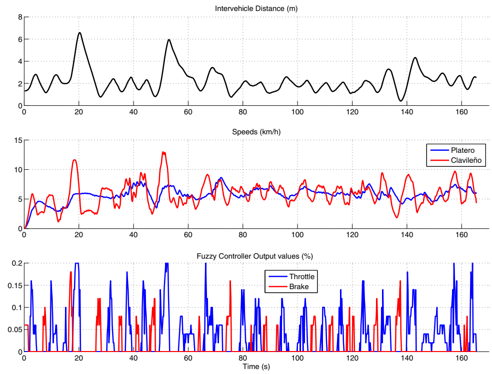


**Fig. 4.** Adaptive speed control experiment

## 4.2 Adaptive Speed Control

Figure 4 shows the behavior of the adaptive speed fuzzy controller at very low speeds. The upper plot depicts the gap between vehicles, that is, the separation distance between them. The middle plot shows the speed of both vehicles during the experiment – blue line for the leading vehicle and red line for the trailing one – and, the lower plot represents the normalized output of the ORBEX fuzzy controller over the actuators (see [9] for details).

One can appreciate how the speed of the leading vehicle is slightly higher than $5km/h$ during the experiment. Taking into account both vehicles are gas-propelled vehicles – and, consequently, the highly non-linear dynamic of this kind of vehicles at these speeds – the inter-distance is maintained during most of the time in values lower than $2m$ with maximum values of $6m$ and minimum values higher than $20cm$ to prevent a collision.

## 4.3 Crossroad

Figure 5 presents the behavior of the crossroad fuzzy controller for urban environments. The upper plot depicts the speed of both vehicles – blue line for the vehicle with right-of-way and red line for the vehicle without right-of-way and equipped with the fuzzy crossroad controller – in km/h. The middle plot depicts the distance of both vehicles to the cross point – red line for the vehicle without right-of-way and blue line for the vehicle with right-of-way – and, the lower plot depicts the normalized output of the ORBEX fuzzy crossroad controller over the pedals (see [11] for details). One of the vehicles is automatically driven, the other – the vehicle with the right-of-way – is manually driven.

At the beginning of the experiment both vehicles are driven at similar speeds – close to 20 km/h – and the distances to the cross point are similar. In second 10, the fuzzy crossroad controller reduced the speed of the automatic vehicle in order to permit the other vehicle to cross. About second 16, the vehicle with

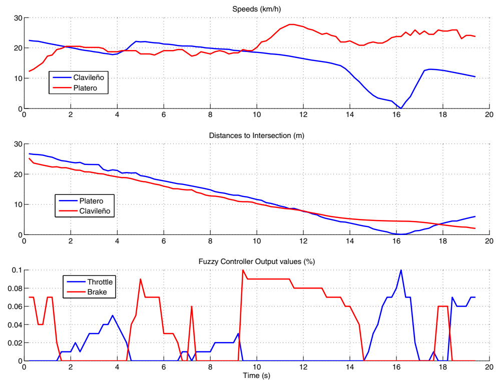


**Fig. 5.** Crossroad experiment

right-of-way crosses the intersection and, then the vehicle equipped with the crossroad fuzzy controller accelerates to cross safely.

## 5 Conclusions

This paper has presented the developments of the AUTOPIA program toward a safer road transport vehicles. In spite of the final target – a fully-automated traffic control system – can be considered a long-term goal, the presented results constitute an excellent starting point toward intelligent vehicles driving in intelligent roads.

Several controllers have been developed to face some of the most important problems in the road transportation as cruise control and adaptive cruise control at low speeds and intersection management with excellent results. These controllers have been tested using a prototype autonomous vehicle developed by the AUTOPIA program in a private driving circuit that emulates an urban traffic area. The real results obtained are promising but there is further room to improve these results searching the final goal: no accidents in roads.

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