Crossroad Cooperative Driving Based on GPS and Wireless Communications

José E. Naranjo, Ricardo García-Rosa, Carlos González, Teresa de Pedro, Javier Alonso, and Javier Vinuesa

Instituto de Automática Industrial (CSIC), Ctra. Campo Real, km. 0,200
La Poveda – Arganda del Rey, 28500, Madrid, Spain
{jnaranjo, ricardo, gonzalez, tere, jalonso, jvinuesa}@iai.csic.es
http://www.iai.csic.es/autopia

Abstract. Autonomous vehicles have the capacity of circulating much in the way humans drive them, but without the inherent limitations of people driving. A second step in the development of these kind of vehicles is to add the capacity to perform cooperative driving with other cars to them, autonomously as well manually driven. The aim of this paper is to describe a new kind maneuvers for autonomous vehicles: intersection dealing capability. In our work with autonomous vehicles, we have developed an automatic driving system based on artificial intelligence, with the ability to perform automatic driving in stand-alone routes as well a limited cooperative driving, with some maneuvers controlled: Adaptive Cruise Control (ACC) and overtaking. In this paper, we develop an extension of the cooperative driving system, adding the capacity to deal with road intersections to the cybernetic driver. We have defined a set of cases of use and we have implemented a first prototype of the simplest one, that is the crossing of a priority road. Some experiments have been carried out, using our mass produced autonomous vehicles, equipped with onboard computers, GPS receivers and wireless networking.

Keywords: Autonomous vehicles, fuzzy logic, intersection management.

1 Introduction

In the year 2005, 41,600 people died in road traffic accidents in the European Union. Some 1.9 million people were injured, some of them severely. The economic damages generated by traffic accidents were estimated at €200 billion, corresponding to approximately 2% of the European Union's Gross National Product. In order to solve this problem, European Commission has taken the challenge of reducing by one half this cipher by the year 2010, mainly applying new information and communication technologies. One of the most dangerous maneuvers is the circulation through road intersections and the various modalities of priority and directions. In the USA, 8,703 accidents were happened in intersections in the year 2005, causing 26,734 victims (U.S. DoT Fatality Analysis Reporting System (FARS)).

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The research on intelligent vehicles for intersection management is actually a technological challenge, with some groups working in this area worldwide. The philosophy is the integration of vehicle-infrastructure components and functions into cooperative intersection collision avoidance systems (CICAS, US DOT CICAS Program, http://www.its.dot.gov/cicas), using wireless communication technology. Some developments have been carried out as driving aids for augmenting the safety in roadway intersections. In California PATH Program some Intersection-Decision-Support systems have been developed in order to advise the driver in one of the most critical situations: left turn across path with incoming vehicles [1], and some working scenarios to test these systems have been defined [2]. More USA research are described in [3]. In Europe, several projects of the 6th FrameWork Program (FWP) deal with these driving aids. That is the case of Intersafe Project, where an ADAS is under development to detect a potentially dangerous situation in road intersections and to warn the driver [4].

A second step in the road intersection technological applications is the partial or total automation of the vehicle in these kind of situations. In the Intelligent Control Systems Laboratory of the Griffith University, in Australia, some autonomous vehicles, Cybercars, have the capability of performing an automatic route and dealing with basic intersection scenarios [5]. Another full autonomous vehicle driving application is that of the INRIA IMARA group in France. In this case and also using Cybercar vehicles, first steps in automatic intersection management are being carried out, allowing the cooperation of two of these cars in giving the way in intersections, using laser sensors and communications [6].A first simple case of use has been implemented.

In this paper we present the approach of the AUTOPIA Program of the Industrial Automation Institute of Spain for automatic driving in roadway intersection, based on GPS and wireless communications. We deal with the two simplest cases, in intersections in which the autonomous vehicle is circulating on a non-priority lane. These two cases of use are: the situation where a car is stopped in a priority lane and the autonomous vehicle circulates through the non-priority one and the situation where both cars are circulating in collision trajectory, with the autonomous going along the non-priority lane. Depending on its speed and position and the speed and position of the vehicle circulating over the priority lane, the autonomous driving system decides whether to stop or to continue the route. Some real experiments have been executed showing the performance of the system.

2 Vehicle Instrumentation

The AUTOPIA autonomous vehicle used in this work is a Citroën Berlingo van whose actuators have been automated. The throttle is managed directly by sending electronic analog signals to the gas control unit of the car. Brake is controlled using a DC motor engaged to the pedal through a pulley and commanded by a power/control card. Both elements are managed from an onboard computer where the control system resides that uses the AUTOPIA automatic driving architecture.

The sensorial input for automatic driving is provided by GPS and wireless communications. The automatic driving system is based on fuzzy logic and is able to determine whether the vehicle has to stop and give the way to the priority one or to continue the route because the other vehicle is far enough to cross the intersection with safety.

3 AUTOPIA Automatic Driving Architecture

When designing an architecture that emulates human driving, we have to look at how humans organize the driving task and what operations they perform.

According to psychologists, human driving can be divided into three activity levels, depending on the attention, resources and perception that are applied. These are the strategic, tactical and control levels [7]. The strategic level includes planning, for example, choice of the best route to reach a destination. The tactical level comprises the execution of complex maneuvers like stopping, overtaking, giving way, etc. Finally, the control level refers to basic actions to keep the car on the right trajectory: moving the steering wheel, pressing the throttle or brake. These levels are ranked in descending order of complexity. This implies that the higher the complexity the more reasoning is needed and the less reactive the system is.

A control system based on human behavior that will support automated operation has to be built around an architecture paradigm. In our case we have chosen Michon [7] model, implemented as a hierarchical architecture, capable of supporting automatic driving and that can be upgraded to deal with other maneuvers that conform to human driving scheme. In our case the strategic planning stage has been taken over by manual user route selection. Then, our architecture is divided into six elements as shown in Fig. 1.

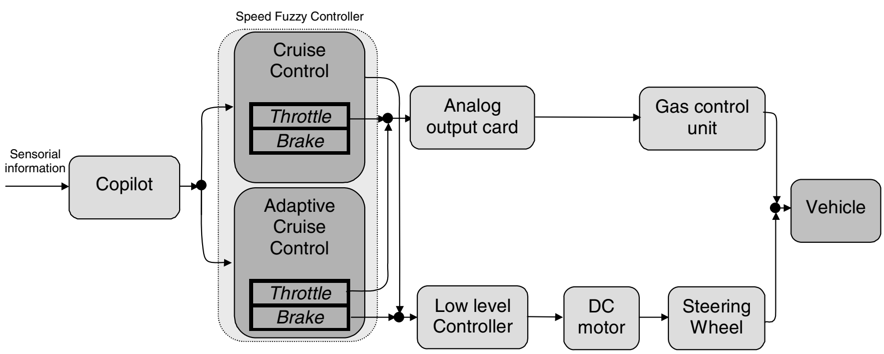

Fig. 1. Automatic speed control architecture

The first module is named copilot and emulates the tactical layer of human driving. It is a decision-making module whose mission resembles the job of a rally driving copilot. It tells the driver when the vehicle is entering a bend or a straight part of the route, when to increase or decrease target speed or when it is necessary to yield, controlling the sequence of operations to be carried out. Usually, the copilot manages the target speed with which the autonomous vehicle has to circulate though a segment of the road. It has also to select whether this speed control is simple (cruise control) or it is necessary to adapt the speed in order to keep a safety distance from a precedent slower vehicle. In the case of intersection management, copilot aim is to manage the target speed of the vehicle, stopping or reducing its speed in the situations where it is necessary to give the way to another car that circulates in the other road of the intersection. Then it chooses between two kinds of speed behavior controllers: CC and ACC. These controllers represent the control layer of human driving and are modeled using fuzzy logic. This technique applies the knowledge of an expert operator, in this case a human driver, to control the equipment [8]. Another advantage is that complex mathematical models [9] are not needed to manage the equipment. This is a very useful feature where hard nonlinear systems, like vehicle throttle and brake control, are concerned. In other words, by applying fuzzy logic to control the speed of a car, we are modeling driver behavior and not the vehicle itself.

The throttle actuator consists of two additional modules: an analog output card that generates a proportional signal of the throttle fuzzy controllers output and the car gas control unit that selects the power effected by the motor according to this signal.

The brake management is somehow different. The third architecture module is the low-level controller. Its mission is to receive the target turning angle from the active fuzzy controller and to generate the appropriate control signals for the motor to move the brake. A PID, tuned to manage the DC motor and attached to the brake pedal, forms this low-level controller.

The fourth, fifth and sixth architecture modules are formed by the actual DC motor engaged by a pulley to the brake pedal.

4 Cases of Use

In this paper we consider two cases of use of the intersection management controller. The first scenario is the situation where the autonomous vehicle circulates through a non-priority lane towards the intersection while a second vehicle is stopped in the middle of the intersection in the priority lane. The second scenario is more complex. In this, a both cars circulate in a colliding trajectory and the automatic nonpriority one has to stop in order to yield the priority one.

4.1 First Case of Use

In figure 2 the configuration of this case of use,, the first scenario that must be solved by our automatic intersection situation manager is shown. The gray car represents the autonomous vehicle and the white one represents a car stopped in the center of an intersection. This is, for example, the case of a car that wants to turn to the left in the intersection or traffic congestion.

The automatic driving system controls the speed of the car, using digital cartography as reference. The GPS position also appears in the cartography of the intersection and the coordinates and the width of the cutting road. This information is used to reference the position of other vehicles from our route.

Once known the ego-position and the cartography of the involved roads, we can define a “collision area” as the portion of road, on the intersection, where a car on the priority lane can represents an obstacle in the route. It is, in this case, the piece of road where both lanes are overlapped.

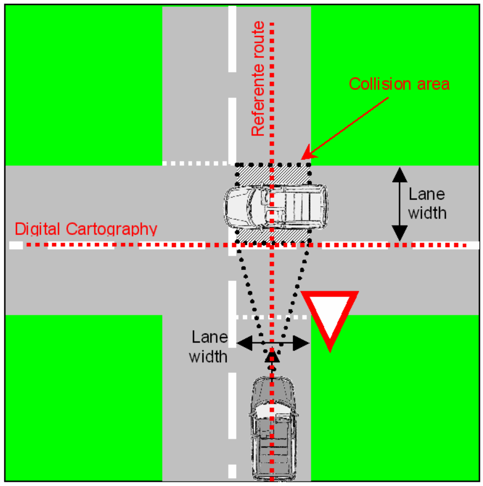

Fig. 2. Graphical representation of the first case of use of the automatic intersection management system

Once the collision area is located, the vehicle decides whether to stop through the environment information received from the WLAN: the GPS position in real rime and a timestamp for synchronizing the message reception.

The algorithm installed in the Copilot control module is in this case very simple: if the GPS position of the priority car is into the collision area and its speed is 0 km/h then stop at a safety distance. Else, continue route.

This system has been implemented and installed in our autonomous vehicle, executing a set of real experiments as the one shown in figure 3. In this case, there is a car stopped in the middle of the right lane, direction to the east, of the horizontal road (priority), manually driven and represented in the figure with a black triangle.

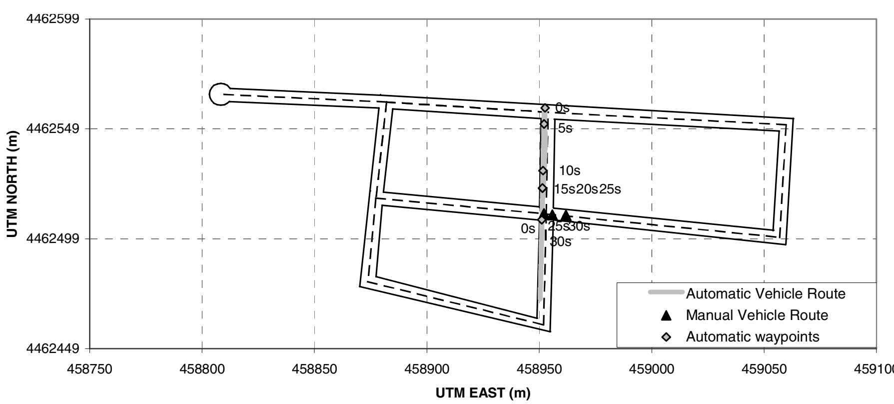

Fig. 3. Experiment of automatic intersection management. First case of use.

Autonomous vehicle trajectory is represented by a gray line and its temporal positions with a rhomboid. It starts its route in colliding trajectory, south direction, through the left lane of the road at 15 km/h. It receives the position of the other car by the wireless LAN environment and placer it in the collision area. When the autonomous vehicle is near enough the intersection (about second 15), the algorithm considers that it is at a safety distance and stops the car. At second 25, the stopped car starts moving and, when it departs from the collision area, the autonomous vehicle control system detects it and continue the route and cross the intersection without more interruptions.

4.2 Second Case of Use

Once solved the simplest case of use, we extend it to solve a more complex situation too. In this case, the intersection management system for autonomous vehicles has to deal with this situation when other vehicle approaches the crossroad in colliding trajectory (figure 4), circulating through a priority road (horizontal).

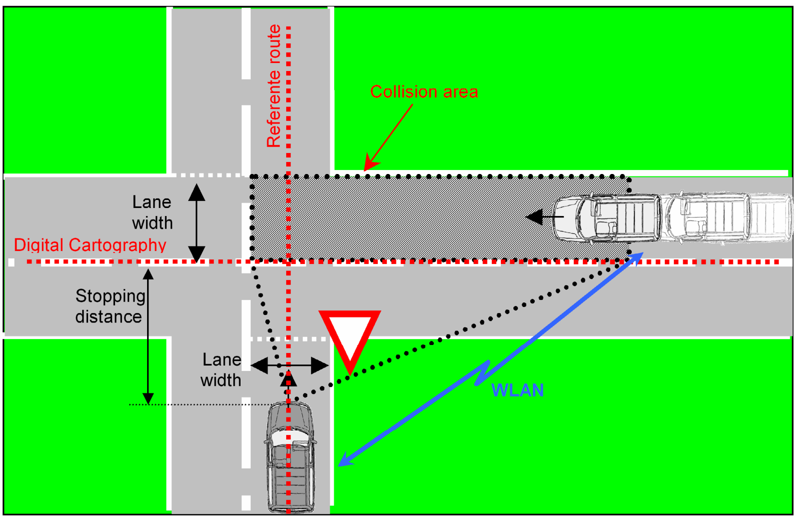

Fig. 4. Graphical representation of the second case of use of the automatic intersection management system

In this case, the gray vehicle is the equipped one that performs a guidance based on GPS. It also considers the cartography of the influence zone, detecting an intersection and a road that cuts its trajectory. Now, we redefine the collision area as the piece of the circulating lane of the priority road that start in the overlapping section up to a preset distance.

The control system, also knows the position of the other vehicle transmitted through the WLAN. Then, the yield algorithm is: *IF* the speed of the priority vehicle is not 0 (vehicle not stopped,) *AND* it circulates in colliding route *AND* it is in the collision area, *THEN* stop at a safety distance. *ELSE*, continue route.

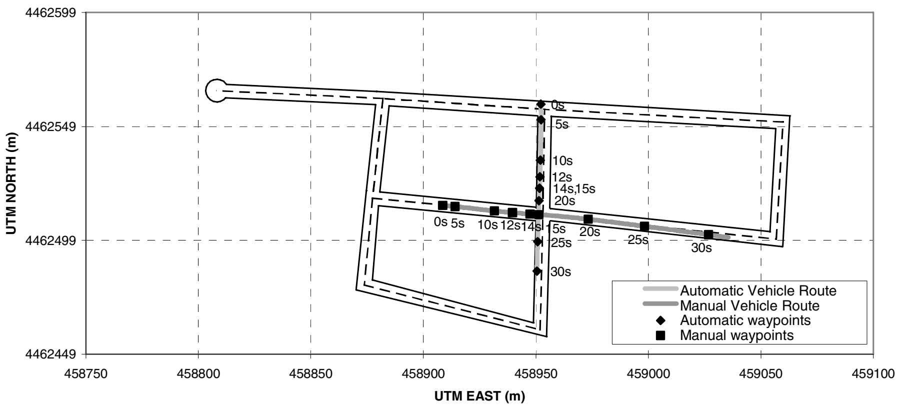

Fig. 5. Experiment of automatic intersection management. Second case of use.

Some experiments have also been carried out in order to demonstrate the feasibility of this system. In figure 5, a schema of the Industrial Automation Institute private testbed circuit is shown, considering the central horizontal road as priority and the central vertical as non priority. Manually driving vehicle circulates through the right lane of the priority road in direction to the East and its trajectory is represented by a dark gray line. Autonomous vehicle circulates through the non priority road, towards South, and its trajectory is represented with a light gray line. Rhomboidal an squared points represent the positions of both vehicles at the same instants from the beginning of the experiment. Both cars circulate about 15 km/h and they follow a collision trajectory.

The automatic intersection management system installed in the vehicle that circulates in the vertical road detects the other vehicle from the beginning of the experiment. It is circulating in a collision route, approaching to the center of the intersection. However, the vehicle is not in the collision area so no action is taken by the equipped car. From second 10, priory car enters in the collision area and the nonpriority one control system begin to take action, reducing speed until the car stops at second 14. From second 12 to 16, the priority the priority car is in the collision area and the equipped one is stopped at a safety distance. From second 16, the priority car surpasses the intersection; now, the way is free and the non priority can continue its route normally.

5 Conclusions

Two case of use for automating the intersection maneuver with ongoing traffic has been studied, implemented and tested. With this equipment, It is feasible to add to autonomous vehicles the capability of automatic intersection management. The required data to achieve this maneuver is: real time GPS position of the vehicles on the road, speed of the vehicles of the road, a digital cartography of the driving route, GPS timestamps for message synchronization.

In order to continue this work, our aim is to extend the behavior of the control system in yielding maneuvers. In these experiments, only stopping is a considered maneuver in order to respond a yielding. As future work we consider to reduce the circulation speed, optimizing the road occupancy and avoiding time looses in the trajectory following.

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