The Alliance of Global Navigation Satellite Systems and Fuzzy Logic in Unmanned Cars

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Abstract

This paper presents a fuzzy control application in the unmanned driving field. Two electric cars have been conveniently instrumented in order to transform them in platforms for automatic driving experiments. The core of the guiding system is based essentially on an alliance of global navigation satellite systems, by now a centimetric DGPS, and on board speed and steering fuzzy controllers.

Keywords: satellite based navigation, fuzzy control, unmanned driving

1 Introduction

There are a lot of Information Technologies that have been integrated in car industries; [1] and [2] are good references to know the new devices that are coming now and the ones that will come in the future.

Aiming at creating basic vehicle automatic driving techniques, the alliance of global navigation satellite systems (GNSS) and fuzzy logic is a good choice, specially if the guideline is to achieve a nuclear driving system with minimal resources, around which new modules can be added for specific applications. The results presented in this paper show that a system that reasons with fuzzy logic and perceives with GNSS is simple, flexible and powerful to attain the proposed aims.

It has been already verified that fuzzy controllers are good tools to model and perform driving tasks [3]. Since the beginning of fuzzy logic Pr. Zadeh pointed at parking a car as one task to be got down to fuzzy logic. Namely, in this work the vehicle controllers have been implemented over a powerful system [4], in which the fuzzy rules for the control commands, are conditional sentences close to the natural language. This closeness allows to design fuzzy controllers to neither computer nor control experts.

On other hand the global navigation systems based on artificial satellite are good for guiding vehicles outside, because their data are robust, easy to process and enough to give information to the steering and velocity control systems. In a first approach the sensors used to drive robots can be used to drive vehicles. In practice, none of the most common robot sensor -ultrasonic, infrared, laser, radar, compass, and vision, ... etc.- are enough to provide by itself the data needed for the driving system.

Resuming, fuzzy logic allows to model an expert knowledge based system to implement basic driving techniques and GNSS allows acquiring the needed data of the environment. The result is applicable to unmanned vehicles in non-urban environments and to assisted driving in urban environments.

2 Platform description

According to the intended applications the following experimental facilities has been installed: a) a test bed circuit of six streets with crosses, of about 1 km of length and 6 m of width, simulating an small urban quarter, b) a GPS base station, and c) an aerial Ethernet network [5], that substitutes the usual radio to get differential corrections and can be used also for communication among vehicles.

Figure 1. View of the circuit

The vehicles in use are two commercial electric models, acquired believing that they would be easier to instrument than the conventional ones. The main differences with the conventional vehicles are in the throttle and gearshift. The throttle is a potentiometer, which acts upon the speed regulator and is actuated by the pedal. There is not mechanical gearbox and only forward and reverse motion can be selected.

As it has been said in the introduction, the vehicle equipment is the minimal required to control the steering and velocity. It consists of a GPS receptor, a DC motor attached to the steering wheel, an electronic circuit to activate the throttle signal and to acquire the tachometer signal and an industrial PC in which the control software is executed.

Recently a vision camera has been installed, it allows to extend the situations that can be managed by the controllers, in particular to avoid obstacles in the road. The vision procedure is full of promise, it does not need lines to detect the road and is rather robust with respect to the light conditions, but until now it has not been integrated in the fuzzy controllers [6].

3 Logical description of the system

The guiding system consists of several modules, fuzzy controllers forming the main one. The others are, a map of the circuit, a user interface and a communication module.

The fuzzy controllers are based on a universal fuzzy control system designed [7], implemented in one's turn, on a fuzzy coprocessor [4]. The main feature of this control system is its ability to deal with fuzzy modifiers, namely *more than* and *less than*. It increases the linguistic meaning of the rules, what has two advantages: reducing the number of rules and bringing them near to phrases of natural languages.

The function of the map is to provide a geometrical representation of the test bed circuit. Thus, it is possible to make a correspondence between a list of street names, defining the desired route, and a sequence of straight segments, a polygonal line defining the route of reference. The internal representation of this reference is the north and east UTM coordinates of its vertices, obtained from the GPS receptor.

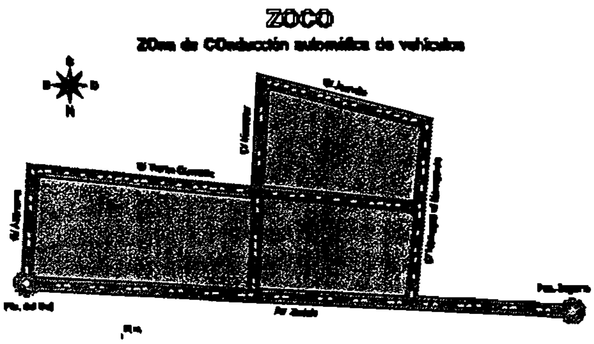

Figure 2. Realistic map of the circuit

The user interface is very simple by now. Its main function is to form the route of reference from the desired route and to fire the execution of the control module.

4 System performance

From a functional point of view the control module starts with an initialition phase, in which the limits of the angle of turning of the steering wheel are normalized between -1 and $+1$. Then the module is ready to begin the cruise. It executes two fuzzy controllers; one acts upon the steering wheel to track each segment and the transitions among them and other acts upon the pedal to adapt the speed [7].

The aerial network allows communicating each vehicle with the GPS station and with other vehicles situated in the circuit.

4.1 Speed fuzzy controller

The aim of the speed fuzzy controller is to guarantee that the car moves at the desired velocity. The inputs to the controller are the speed_error and the acceleration, both are obtained from the vehicle tachometer, and the output is a change in the voltage of the throttle signal. (An increment in this voltage is equivalent to increase the pressure on the throttle and a decrement is equivalent to decrease it).

The following are examples of input definitions. The speed_error has a unique linguistic value, zero, and numbers that follow are the parameters of a triangle, its membership function, measured in km/h. The definition of the acceleration is similar, in this case the parameters are measured in km/h/s. Finally, the output throttle has two linguistic values and their membership functions are singletons[1].

speed_error = {zero: -15, 0, 13}
acceleration = {zero: -17, 0, 13}
throttle = {down: 1, up: -1}

The following are examples of speed control rules. The words in cursive are key words of the user language interface.

If speed_error *less than* zero *then* throttle down
If acceleration *more than* zero *then* throttle up

The route followed by this controller has shown an error less than 0.5 km/h while a constant speed has been maintained.

4.2 Steering fuzzy controller

The steering fuzzy controller is in charge of tracking the reference segments as well as the transitions among them. This is accomplished taking as inputs the car orientation angle and the separation of the car from the reference segment; both variables are computed from the data acquired by the DGPS. There is only one output, the direction of wheels.

The following are the schematic definitions of these variables, their fuzzy values and the correspondent membership functions.

separation = {null: -5m, 0m, 5m}
angle = {zero:-5°, 0°, 5°}
wheels = {sn: -3°, sp: 3°}

Two basic driving strategies are defined in two fuzzy contexts, which are needed to emulate the driving behavior of human beings when they follow straight or curve trajectories. In straight line driving the speed can be high and the steering wheel has to be turned slightly and smoothly; on the contrary in closed curves the speed is low and the steering wheel has to be turned widely and rapidly. The rules of the defined fuzzy contexts match these observed driving modes and are applied alternatively to track the route.

[1] In this application all the linguistic values of the output variables are singletons.

The following rules are for tracking straight lanes:

If angle *less_than* zero *then* wheels sp
If angle *more_than* zero *then* wheels sn
If separation *less_than* null *then* wheels sp
If separation *more_than* null *then* wheels sn

To track curve lanes the fuzzy context is a little more complicated, in particular a new input is taken into account, the steering variable, that stands for the angular position of the steering wheel. Its fuzzy value, centered, is defined by a triangular membership function. On the other hand, though the input variable angle and the output variable wheels are the same to track straights or curves, the parameters of their membership functions zero and null are different, to emulate human behaviors.

The following are the schematic definitions of these variables, their fuzzy values and the correspondent membership functions.

separation = {null: -5 m, 0 m, 5 m}
angle = {zero: -5°, 0°, 5° }
steering = {centered: -5°, 0°, 5° }
wheels = {bn: -30°, bp: 30°}

The following rules are for tracking curves:

If angle *less_than* zero *then* wheels bp
If angle *more_than* zero *then* wheels bn
If separation *less_than* null *and*
steering *more than* centered *then* wheels bp
If separation *more_than* null
and steering *less than* centered *then* wheels bn

4.3 Results: A run by the quarter

To do this experiment the two precedents controllers have to be applied alternatively [8]. In this case the car route is fixed by a list of streets, for instance: Zadeh, Henrique el Navegante, Juanelo, Mercator, Torres Quevedo, Azarquiel, Zadeh 20, where the number means the goal car position, Zadeh Street at 20 meters from the origin.

The turning maneuver consists in changing the reference line and braking, if the velocity is higher than 6 m/s. like a human driver, the fuzzy controller begins to turn before the car arrives to the proper corner. In other words, the actions of braking and changing of reference must begin some meters before the corner. This value has been found experimentally according to mechanical features of the car and the route conditions; 10 m if the car goes along the center of the street and 12-m if the car has to maintain the right lane.

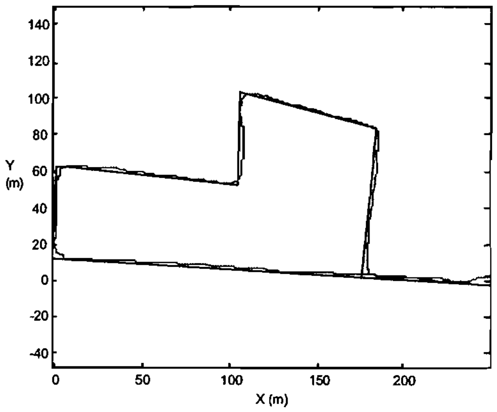

Figure 3. Real and reference routes superposed

The results of the experiment show that the car recovers the initial separation and maintains the reference line attaining a speed of 65 km/h.

5 Conclusions

An autonomous navigation system based on cooperation between GNSS and fuzzy controllers has been designed and implemented on commercial vehicles for unmanned transport applications. The techniques developed can be applied also to provide assisted driving.

Current tests are being carried out in an environment similar to an urban quarter to enhance performance and robustness.

Up to now the real experiments have been done with one vehicle, but also simulated experiments have been done with several vehicles, namely circulation in platoon and overtaking [8], what means that the guiding system is able of dealing with them.

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