Vehicle automatic driving system Based on GNSS

T. de Pedro* (tere@iai.csic.es), R. García Rosa* (ricardo@iai.csic.es),
C. González* (gonzalez@iai.csic.es), J. E. Naranjo* (jnaranjo@iai.csic.es),
J. Reviejo* (jesus@iai.csic.es), M.A. Sotelo**(michael@depeca.alcala.es),

** Instituto de Automática Industria, CSIC, La Poveda, 28500 Arganda del Rey,Madrid, SPAIN*
***Departamento de Electrónica, Universidad de Alcalá de Henares, Madrid, SPAIN*

1 INTRODUCTION

There are a lot of Information Technologies that have been integrated in car industries. The papers The News [1] from Ford and The Tomorrow's World [2] from FIAT are good references to know new devices that are coming now and the ones that will come in the future.

Ford distinguishes between classical and smart electronics boarded on cars. Computers and advanced electronic has been in cars for decades, they control and communicate with devices that operate wholly within the vehicle, but are not considered smart electronics. True smart electronics sends and receives information outside the vehicle and deliver feedback to the driver and/or the device. Smart electronics include adaptive cruise control, radar based sensing aids, off board navigation systems and electronic messaging among others. A list of today technologies is included in this rapport and, more interesting, a list of the next wave technologies.

The FIAT report presents the Lancia Nea, a prototype shown in the exhibition circuit of Orbassano, near Turin. The key idea in the Nea design is that a vehicle would be more than a mean of transport, it would provide as much driver and occupant support as possible. The Nea is endowed with vision and radar systems -eight cameras, one long range radar and six short range radars. But the novelty in the Nea car is that the data given by the sensor systems are combined to provide the size and range of obstacles in the environment. This information is processed to compute various scenarios. If static or dynamic obstacles are detected a computer controls brakes, engine and steering. Gianfranco Burzio, director of the on board information systems at FIAT, thinks these obstacle avoidance systems are seven years away.

Both FIAT and FORD and other companies are looking for advanced driver assistance systems, ADAS, based on GNNS and road geometry data; in this case the car will react to precise road conditions. The time that Mr. Burzio expects to get it is ten years.

This paper explains our first attempts to control a car with data coming from a GNSS and vision camera.

2 FACILITIES

A test bed circuit has been built in IAI area; it consists of a set of six streets that reproduce a small quarter with crosses and a round square, the Sugeno Square. The total length of the circuit is about 1 km and the width is six meters.

There are two CITROËN BERLINGO electric vans equipped with industrial computers, motor board controllers, a centimeter precision DGPS receiver and a communication board. A central station spreads the differential GPS corrections. An aerial Ethernet network substitutes the usual radio to get differential corrections.

The only information from the outside came from GPS in the first experiments, now an artificial vision system has been included and the cars are able of dealing with unknown obstacles.

Figure 1. View of the circuit

3 CONTROL STRATEGIES

The driving strategies are implemented by fuzzy systems [3] [4]. General speaking, a fuzzy controller converts the raw data from the sensors in linguistic variables, that describe the relevant features of the environment, and it models the behavior of a human driver by means of a set of IF ... THEN ... rules. The execution of a fuzzy controller gives the values of the output variables [5], in our case the steering angle and the acceleration value.

As an example, the figure 2 contains the linguistic description of a problem, that is the variables representing relevant features of the environment and two fuzzy rules to compute the required acceleration value.

Environment

corner = {near, far};
speed = {nominal};
car_ahead = {near, far};

Rules

IF corner near AND speed
MORETHAN nominal OR car_ahead far
THEN pedal down;
IF corner far AND car_ahead far
THEN pedal up;

Figura 2. Some variables and control rules

The guiding system is based on a universal fuzzy controller developed by authors [6]. Some remarks would be done: a) It can deal with many shapes of membership functions but, to speed up the defuzzification procedure, only triangular and trapezoidal shapes are used for inputs and singletons for outputs. b) The use of fuzzy modifiers, like MORETHAN in the example [7], increases the expressive power of rules, bringing them near to phrases of natural language.

4 GEOMETRICAL REPRESENTATION AND GNSS

As the circuit simulates an urban quarter, the streets have symbolic names, so a route can be fixed symbolically. To do it a map of the circuit has to be built, in such a way that each lane of a street is mapped on a line of reference situated in the middle.

To build the map a car with a GNSS and manually driven goes by the circuit, the positions provided by the GNSS are used to know the coordinates of the reference line. The GNSS system used is a differential GPS of high precision, it consists of a base placed on the roof of the IAI building and the receivers boarded on the cars. Several kinds of GPS are been tested to determine if their performances are enough to drive cars in urban environments.

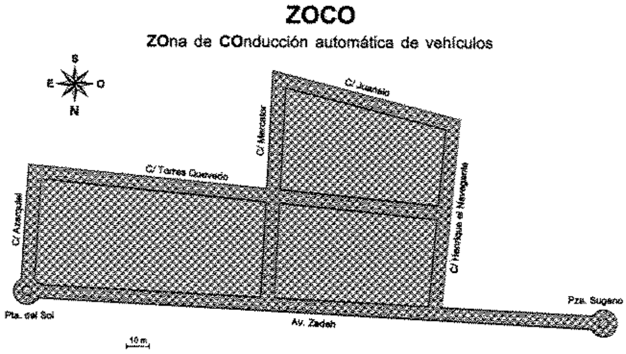

Figure 3. Realistic map of the circuit

5 EXPERIMENTS

All the experiments have been realized with a sample rate of 0,2 s and the maximum angular speed of the steering wheel, 5°/s.

5.1 Tracking of straight lanes

In this experiment the car has to run 250 m along the longest street, Zadeh Street, starting from a position 1m away the reference line of the lane. The inputs to the control system are the distance of the car to the reference line, *displacement*, and the car orientation, the angle between the axis of the car and the lane direction, *angle*; there is only one output, the direction of wheels, *wheels*. It follows the schematic definitions of these variables, their fuzzy values and the correspondent membership functions.

The *displacement* variable is defined by a unique fuzzy value, *null*, like a triangular function:

null = {-5m, 0m, 5m}

The *angle* variable is defined by a unique fuzzy value, *zero*, like a triangular function:

zero = {-5°, 0°, 5°}.

The *wheels* variable is defined by two fuzzy values, small_negative, *sn*, and small_positive, *sp*, represented by two singletons (the control program transforms these values in degrees multiplying by 30°):

$sn = \{-0.1\}$
$sp = \{+0.1\}$

The set of control rules is:

IF *angle* LESSTHAN *zero* THEN *wheels sp*
IF *angle* MORETHAN *zero* THEN *wheels sn*
IF *displacement* LESSTHAN *null* THEN *wheels sp*
IF *displacement* MORETHAN *null* THEN *wheels sn*.

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.

5.2 Behavior in a corner

To accomplish turns the guide system changes the reference line. In our circuit (figure 3) the turns are dramatic because the angles among streets are near 90°, in particular the cross of the streets Henrique el Navegante and Mercator is almost 100°. These strong curves oblige the car to reduce the velocity at 6 km/h, before to turn.

The input variable *angle* and the output variable *wheels* are the same to track straights and to track curves, but, to emulate human drivers, the definitions of their fuzzy values *zero* and *null* are different. In effect, following a straight the car orientation changes less than following curves; the same happen with the orientations of the wheels. So the fuzzy values for these variables are *big_negative* and *big_ positive*, respectively and their definitions, the singletons –1 and +1. Besides to track curves it is convenient to take other input 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.

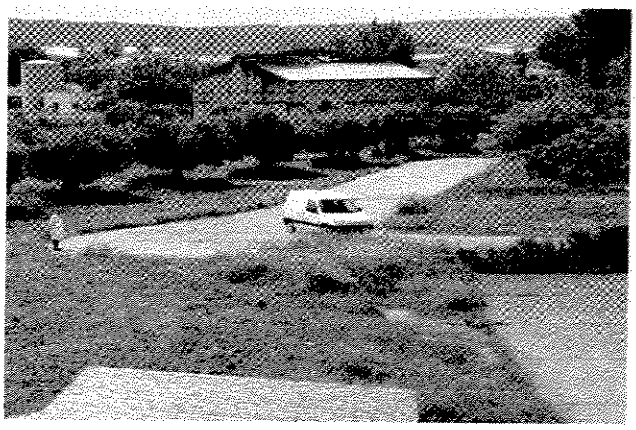

Figure 4. Car turning

The set of fuzzy rules to track curves is:

IF *angle* LESSTHAN *zero* THEN *wheels bp*
IF *angle* MORETHAN *zero* THEN *wheels bn*
IF *displacement* LESSTHAN *null* AND
steering MORETHAN *center* THEN *wheels bp*
IF *displacement* MORETHAN *null* AND
steering LESSTHEN *center* THEN *wheels bn*.

The results obtained are goods when it is considered that streets have one lane, but for streets of two lanes it is difficult keeping the right lane. This means that guiding strategies have to be improved.

5.3 A walk by the quarter

A more complete experiment mixes the two precedents. 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 have to begun some meters before the corner. This value has been found experimentally according to mechanical performances 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.

6 OBSTACLES DETECTION

By now the navigation system explained above is based on GNSS, so obstacles can not be detected neither avoided. To deal with obstacles a computer vision system has been built

Obstacles detection and avoidance is a basic skill every autonomous vehicle must be endowed with in order to prevent collisions. This problem becomes particularly relevant in a complex and non-structured outdoor environment. The main goal is to provide obstacles detection using computer vision. Obstacles will only be searched for in a road portion ahead of the vehicle (where obstacles are more likely to appear) as it makes no sense to avoid obstacles that are out of the road limits. This restriction eases the determination of obstacles. Hence, lane-tracking functionality becomes necessary so as to provide accurate road estimation.

6.1 Road estimation

Previous research groups [8] have widely demonstrated that the reconstruction of road geometry can be simplified by assumptions on its shape. Thus, we use a polynomial representation assuming that the road edges can be modeled as parabola [9] in the image plane. Similarly, the assumption of smoothly varying lane width allows the enhancement of the search criterion, limiting the search to almost parallel edges. On the other hand, due to both physical and continuity constraints, the processing of the whole image is replaced by the analysis of a specific region of interest in which the relevant features are more likely to be found. This is a generally followed strategy [10] that can be adopted assuming a priori knowledge on the road environment. All these well known assumptions enhance and speed-up the road estimation processing [11].

The incoming image is on hardware re-scaled, building a low-resolution image of what we call the Area of Interest (AOI), comprising the nearest 20-m ahead of the vehicle. The AOI is segmented basing on color properties and shape restrictions. The proposed segmentation relies on the HSI (hue, saturation, and intensity) color space [12] because of its close relation to human perception of colors. The hue component represents the impression related to the dominant wavelength of the color stimulus. The saturation corresponds to relative color purity, and so, colors with no saturation are gray-scale colors. Intensity is the amount of light in a color. In contrast, the RGB color space has a high correlation between its components (R-B, R-G, G-B). In terms of segmentation, the RGB color space is usually not preferred because it is psychologically non-intuitive and non-uniform. The scheme performs in two steps:

1. Pixels are classified as chromatic or achromatic as a function of their HSI color values: hue is meaningless when the intensity is extremely high or extremely low. On the other hand, hue is unstable when the saturation is very low. According to this, achromatic pixels are those complying with the conditions specified in equation 1.

$$I > 90 \quad or \quad I < 10 \quad or \quad S < 10 \qquad (1)$$

Where the saturation S and the intensity I values are normalized from 0 to 100.

2. Pixels are classified into road and non-road (including obstacles). Chromatic pixels are segmented using their HSI components: each pixel in the low-resolution image is compared to a set of pattern pixels obtained in the first image in a supervised manner. The distance measure used for comparing pixel colors is a cylindrical metric. It computes the distance between the projections of the pixel points on a chromatic plane, as defined in equation 2.

$$d_{cylindrical}(s,i) = \sqrt{(d_I)^2 + (d_{ch})^2} \qquad (2)$$

with

$$d_I = | I_s - I_i | \qquad (3)$$

and

$$d_{ch} = \sqrt{(S_s)^2 + (S_i)^2 + 2 S_s S_i \cos \Theta} \qquad (4)$$

where

$$\Theta = \begin{cases} | H_s - H_i | \; if \; | H_s - H_i | < \pi \\ 2\pi - | H_s - H_i | \; if \; | H_s - H_i | > \pi \end{cases} \qquad (5)$$

Subscript i stand for the pixel under consideration, while subscript s represents the pattern value. An examination of the metric equation shows that it can be considered as a form of the popular Euclidean distance (L2 norm) metric. A pixel is assigned to the road region if the value of the metric $d_{cylindrical}$ is lower than a threshold T_{chrom}. To account for shape restrictions, the threshold T_{chrom} is affected by an exponentially decay factor yielding the new threshold value Γ that depends on the distance from the current pixel to the previously estimated road model, denoted by d as defined in equation 6.

$$\Gamma = e^{\frac{-Kd}{\hat{W}}} \cdot T_{chrom} \qquad (6)$$

where $\hat{W}$ stands for the estimated width of the road and K is an empirically set parameter. This makes regions closest to the previous model be more likely to be segmented as road.

For achromatic pixels, intensity is the only justified color attribute that can be used when comparing pixels. A simple linear distance is applied in this case, so that the pixel is assigned to the road region if the difference is lower than a threshold value T_{achrom}, similarly affected by an exponential factor, as equation 7 shows.

$$| I_s - I_i | < e^{\frac{-Kd}{\hat{W}}} \cdot T_{achrom} \qquad (7)$$

Once the segmentation is accomplished, a time-spatial filter removes non-consistent objects in the low-resolution image, both in space and time (sporadic noise). After that, the maximum horizontal clearance (absence of non-road sections) is determined for each line in the AOI. The measured points are fed into a Least Squares Filter with Exponential Decay that computes the road edges in the image plane, using a second order (parabolic) polynomial. Using the road shape and an estimation of the road width (basing on the previous segmentation) the exact area of the image where the obstacles are expected to appear can be calculated. Obviously, obstacles are searched for only within the estimated area in the previous iteration. Image 1 depicts an example of lane tracking in which both the road edges and the center of the road have been highlighted.

6.2 Obstacle detection results

Obstacles in front of the vehicle, such as cars, are detected with enough resolution within a safety distance of 10-m ahead of the vehicle, processing up to 15 frames/s. Figure 2 shows a series of images covering a stretch of road where another vehicle appears in the opposite lane. The obstacle and lane positions are determined, as illustrated in the figure, so as to modify the fuzzy controller inputs both for angle and velocity to issue obstacles detection capacity.

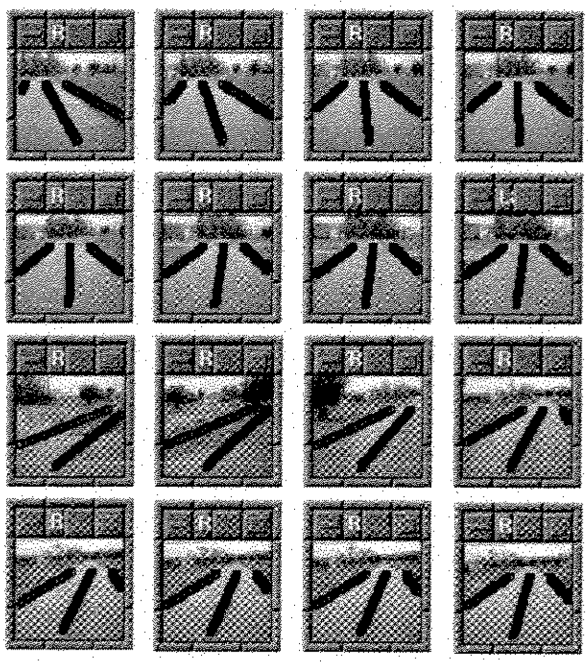

Figure 5. Lane tracking example.

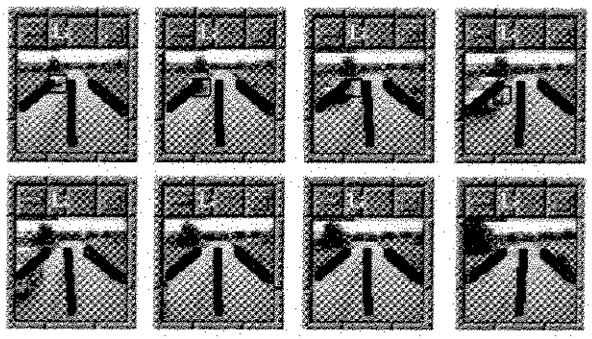

Figure 6. Obstacle and lane determination

6.3 Obstacle avoidance results

The fuzzy controller can avoid obstacles detected along the vehicle path whenever the vision system determines there is enough space to perform the avoidance maneuvering. It starts decreasing speed and modifying the turning response until the obstacle is surrounded. After that, normal tracking is resumed. In case that not enough space is detected, the vehicle stops.

7 REFERENCES

[1] Ford'S In-Vehicle 'Smart' Electronics And Telematics Iniciative in http://media.ford.com

[2] Jesse Crosse, Tomorrow's World, *Automotive World*, January/February 2001, pp 46-48

[3] T. Terano, K. Asai, M. Sugeno, Fuzzy Systems Theory and its Applications, *Academic Press*, 1992

[4] H. J. Zimmermann, Fuzzy Set Theory and its Applications, *Kluwer Academic Press*, 1991

[5] Mun, Dickerso, Kosko, Fuzzy throttle and brake control for platoon of smart cars, *Fuzzy Sets and Systems*, n.84, 1996, pp 209-234.

[6] Ricardo García, Teresa de Pedro, Marco Tulio de Andrade, A Knowledge Base Structure for Fuzzy Controllers, *Proceedings of the 2nd International Conference on Fuzzy Logic and Neural Networks*, Iizuka Japan July 1992, pp 257-260.

[7] Ricardo García, Teresa de Pedro, Modelling a Fuzzy Co-Processor and its Programming Language, *Mathware and Soft Computing*, n. 5, pp 167-174, 1998.

[8] M. Lützeler, E. D. Dickmanns, Road recognition with MarVEye, in: *Proceedings of the IEEE Intelligent Vehicles Symposium '98*, Stuttgart, Germany, October 1998, pp. 341-346.

[9] S. L. Michael Beuvais, C. Kreucher, Building world model for mobile platforms using heterogeneous sensors fusion and temporal analysis, in: *Proceedings of the IEEE International Conference on Intelligent Transportation Systems '97*, Boston, MA, November 1997, p.101.

[10] J. Goldbeck, D. Graeder, B. Huertgen, S. Ernst, F. Wilms, Lane following combining vision and DGPS, in: *Proceedings of the IEEE Intelligent Vehicles Symposium '98, Stuttgart, Germany, October 1998*, pp. 445-450.

[11] M. Bertozzi, A. Broggi, A. Fascioli, Vision-based intelligent vehicles: State of the art and perspectives. *Robotics and Autonomous Systems, 32, 2000*, pp 1-16.

[12] N. Ikonomakis, K. N. Plataniotis, A. N. Venetsanopoulos, Color Image Segmentation for Multimedia Applications, *Journal of Intelligent and Robotics Systems 28, 2000* Kluwer Academic Publishers, pp. 5-20.