A PERCEPTION SYSTEM FOR ACCURATE AUTOMATIC CONTROL OF AN ARTICULATED BUS

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This paper describes the perception system for an automatic articulated bus where an accurate tracking trajectory is desired. Among the most promising transport infrastructures of the autonomous or semi-autonomous transportation systems, the articulated bus is an interesting low cost and friendly option. This platform involves a mobile vehicle and a private circuit inside CSIC premises. The perception system, presented in this work, based on 2D laser scanner as a prime sensor generates local terrain maps, where the major concern lies in detecting and tracking a tunnel guide rail built-in the circuit, by using a hybrid-efficient line extraction algorithm and the obstacle detection to guide the vehicle down the lane.

1. Introduction

The interest in developing fully automated vehicles has occupied important research activities focused on increasing the driver and passenger safety, where control systems take a very significant role [1]. Moreover, the concern of safer, more reliable and mass transportation systems have also grown, leading to Intelligent Transport Systems (ITS) [2-3]. Control of vehicle dynamics has been increasingly investigated over the last 15-20 years [4-5]. Bus Rapid Transit (BRT) systems are a promising transportation system that is becoming very popular and their automation is of major relevance [2].

The Department of Automatic Control has carried out an experimental set-up for research on real-time automatic control of articulated buses, this set-up consist in a mobile platform (the bus, a Volvo BM10) fully instrumented and a special circuit inside CSIC premises [6], for the vehicle guidance the asphalt roads have a built-in tunnel guide rail.

The perception systems is an essential element for these vehicles, the information of their surroundings must be extracted and understood. Both understanding levels are important low and high, to determine the environment structure and whether or not the terrain is drivable. In this work we describe a perception system based on two 2D laser scanners, a hybrid – efficient line extraction algorithm is developed for the tunnel guide rail detection and tracking, additionally the obstacle detection is carried out. The results of the proposed algorithms are also presented and the 3D reconstruction as well.

2. Experimental platform overview

The experimental set-up provides a reliable test bed to carry out research on automatic control of articulated buses. This experimental set-up is used on a private inner road facility located at IAI-CSIC premises. Figure 1 shows the main elements of the overall architecture of the experimental platform using a Volvo B10M articulated bus as its main building block.

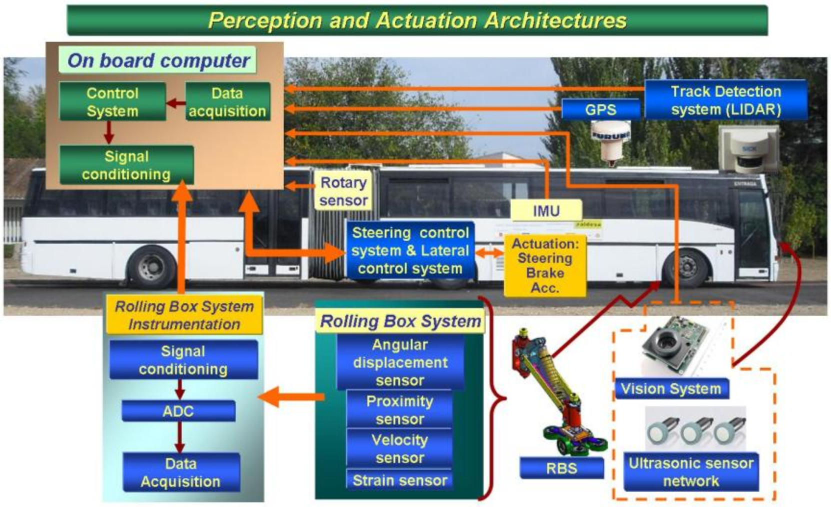

Figure 1. Proposed architecture for perception, actuation and control for the automation of articulated bus.

In Figure 2 a set of pictures of the modified circuit are presented, where the split segment of the built-in tunnel guide rail is 50 mm. wide and 180 mm. depth. Initial experiments are represented in the following figure, the entire circuit in Figure 3(a) and the results of the bus automatic control along the circuit in Figure 3(b). An active control strategy is applied for this experiment that makes the bus central axis conform to the trajectory curvature, the main input data is provided by the RBS system (encoders), also called the mechanical electronic guidance system when it moves through the tunnel guide rail [6].

Figure 2. Partial and panoramic views of the test circuit (385 m. long).

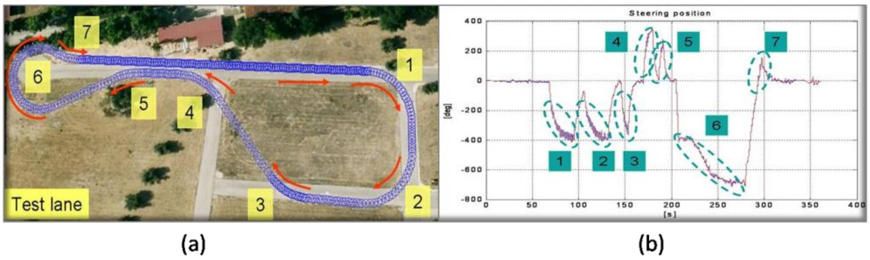

Figure 3. (a)Test lane for buses over the road at IAI-CSIC; (b) Steering wheel position (angle) during an experiment performed on the test lane.

3. Perception system

The system is based on two lasers measurement systems SICK LMS 221 placed in the vehicle front part and longitudinally aligned with its centre; in such way that the devices look diagonally forward and downward at pitch angles of -6º for *laser_obstacle* (range 0º to180º, resolution 0.5º), its position denoted as $X_{obs} = (x_{obs}, y_{obs}, z_{obs})$ and -26º for *laser_rail* (range 40º to140º, resolution 0.25º), denoted as $X_{rail} = (x_{rail}, y_{rail}, z_{rail})$. Both devices are connected through the Quaetech High-Speed RS-422 interface for 500KBaud and the average sampling frequency is 75Hz.

With the intention to perform accurate control guidance of the bus, the precise estimation of the trajectory position is strongly desired, in this case by detecting the centre of the guide rail. Some important considerations, to avoid out of range measures, the look forward distance L_h depends on the conventional lane dimensions and the tunnel guide geometry, in this case, $2200 \ mm. < L_h < 3000 \ mm$. The perspective view effects and the circuit design change the pure shape of the guide rail. And finally, for the lane modelling, the road pieces between the wheels are considered as a similar structure, represented for the centre of the guide rail. Figure 4 shows the acquired raw data of the terrain and remarks on the low resolution data and the complexity of the profile.

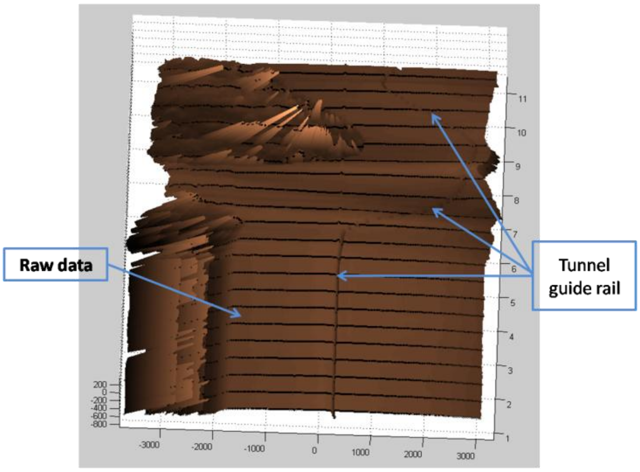

Figure 4. A 3D terrain representation from raw acquired data (top-view).

3.1. *Tunnel guide rail detection*

In this work we present a hybrid algorithm inspired on Split & Merge and Incremental algorithms for the line extraction step (see the comparison of the most popular line extraction methods in [7]). We propose an approach for detection of deformable lines edges from a low resolution data, to detect the tunnel guide rail centre, which is described as two control points (see Figure 5), one placed in the centre of an invisible line of the tunnel top level $P_{top} = (x_t, y_t, z_t)$ and the second one the centre of the tunnel bottom level $P_{bottom} = (x_b, y_b, z_b)$, the local reference frame $\hat{O}_{rail}$ is placed on X_{rail}. However, since the goal is only to detect the tunnel trajectory not the scene reconstruction, the input information can be simplified to two-dimensions, the data projection on *xy*-plane. The procedure of the proposed algorithm is described in Table 1 and the most representative results in Figure 5.

We have run the algorithm over 200 samples; the following images represent the most significant situations, in Figure 5(b) an ambiguous profile, in Figure 5(c) a noisy profile and in Figure 5(d) a data occlusion profile. The system has to be capable to detect the both kind of obstacles, on the road (pedestrian, objects and other vehicles) and possible objects into the tunnel.

Table 1. Description of the line extraction algorithm.

Pseudo-code of the hybrid algorithm for line extraction
1. Sliding window of N points, compute maximum local point P_{max}.
2. Split N from each extreme of P_{max} and start to construct lines from *n* points.
3. If consecutive lines has the same line model merge collinear/overlapped segments.
4. If both extremes fit to the same model (std and local mean) and the segment of P_{max} is bigger than threshold, possible object, else continue (go to 1).

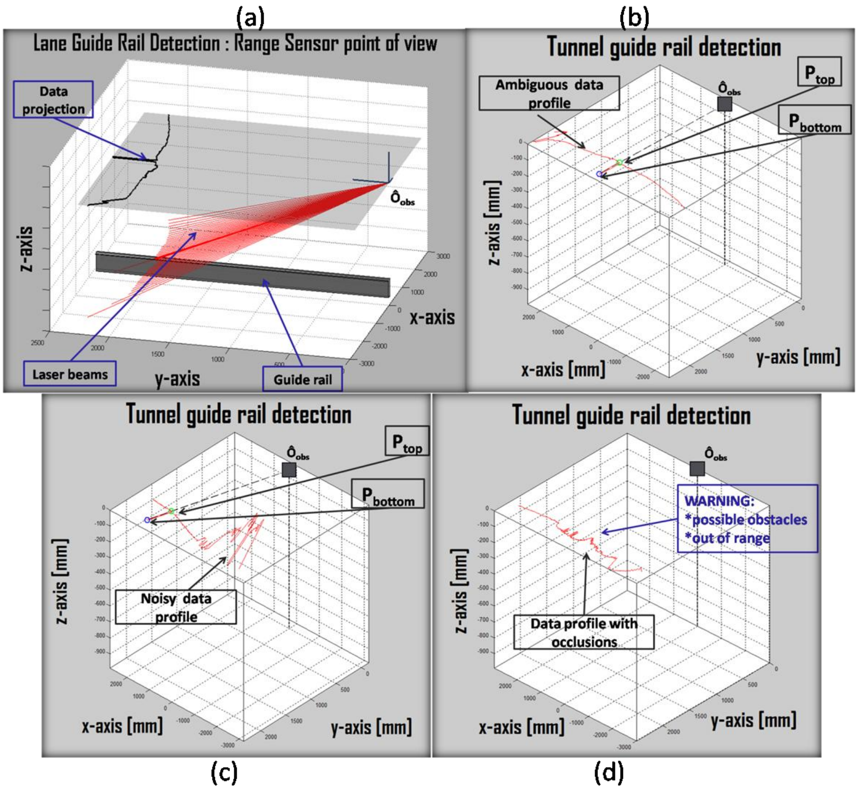

Figure 5. (a) Local *laser_rail* world frame and its variables; (b) Ambiguous profile; (c) Noisy profile and (d) Data occlusion profile.

3.2. *Rail curvature*

In general, in curvature computing, landmarks or lines on the road are extracted using complex methods to obtain legitimate control points, these are calculated from a single image frame [8]. In this work, our system provides two certain control points for each sample, collected due to the combination of the LIDAR sensor and the guide rail geometry. Figure 6 shows the data processing results of the entire test lane, the top and the bottom positions, represented by its deviation angle from the *y-axis* of $\hat{O}_{rail}$. The effectiveness of the proposed rail detection method can be shown when comparing Figure 3(b) and Figure 6, both profiles matches. The steering positions profile, also the inputs to vehicle guidance along trajectory are the reverse of the profile depicted for the previous look ahead local positions of the rail along the trajectory (curves and straights). In Table 2 the experimental results over 150 samples of the complete trajectory are presented (see Figure 3(a)).

Table 2. The Experimental results of the proposed algorithm.

N. samples	True. Pos (%)	False. Pos (%)	Precision (mm)	Precision (deg)
150	98	2.8	+/- 5	+/- 0.87

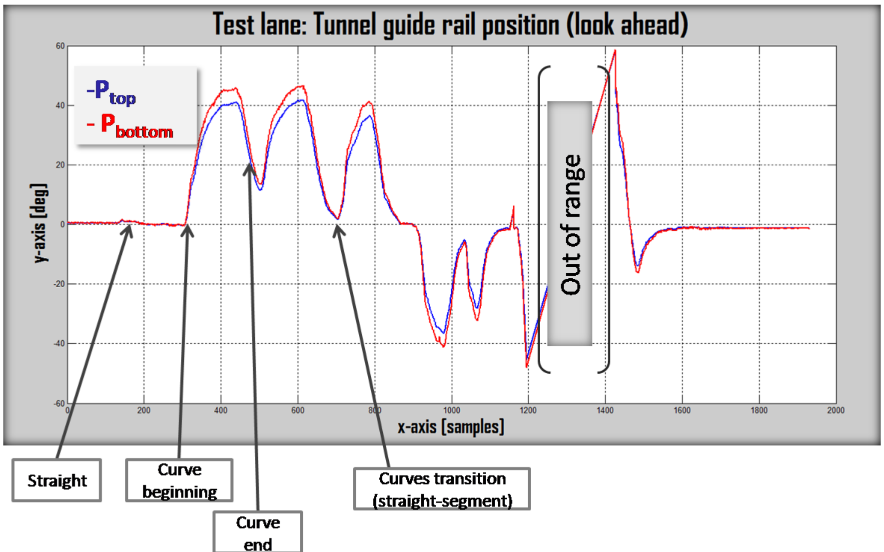

Figure 6. Tunnel guide rail detection, angles at P_{top} and P_{bottom} over the entire trajectory (see Figure 3(a)).

In order to improve the current active automatic control for vehicle guidance, we introduce a curve anticipation approach using a fuzzy logic classifier. This method allows us to mimic the human driving behavior and it has been well-tested for this kind of systems. The human experience and the knowledge of the system and environment are described by Figure 6 and Figure 3. The goal is to identify whether an observed segment is curved or not. We can assume that in every classifying stage, the observed segment dimensions, called Ψ_i, are such that the steering (wheels) angle and the vehicle velocities do not change within the segment boundaries. The segment Ψ_i at least comprises N=10 samples from the current sample S_k to S_{k-10}. The input and output variables of the intelligent classifier are detailed in Table 3 and the initial result in Figure 7.

Table 3. Input and output variables

INPUT	OUTPUT
→ Degree of curve fitting process {1, 2, 3} of $(P_{top})_k \ldots (P_{top})_{k-10}$	→ *b-curve-left*: beginning of a left curve
→ Slope/ tangent to a $(P_{top})_k$	→*e-curve-left*: ending of a left curve
→ $\Delta((P_{top})_k - (P_{bottom})_k)$	→*b-curve-right*: beginning of a right curve
→ State of Ψ_{i-1} {*b-curve-left , e-curve-left, b-curve right, e-curve right, straight*}	→*e-curve-right*: ending of a right curve
	→ straight

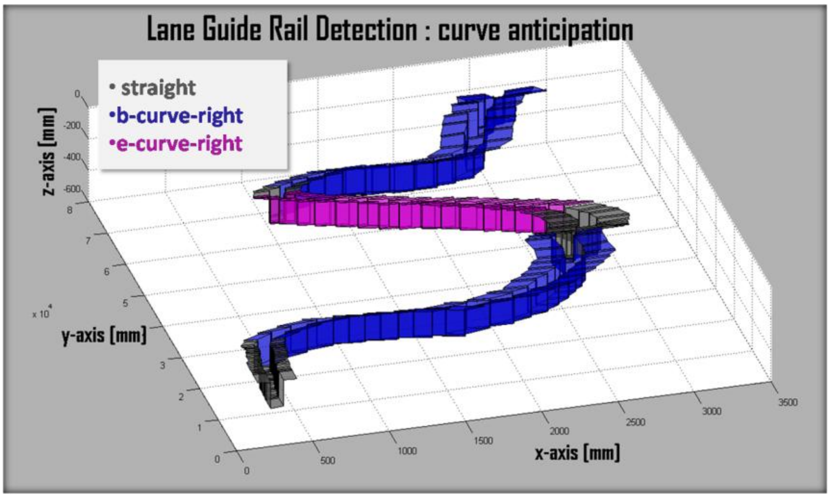

Figure 7. Experimental results of curves anticipation, a 3D representation.

The initial result of the approach, depicted in Figure 7, shows the fitted segments Ψ_i of the N samples and its corresponding state. Since the steering (wheels) angle and the vehicle velocity at every time are known, it is also possible to compute the curvature of the lane based on the tunnel guide trajectory, therefore the high-accurate control strategy for vehicle guidance.

4. Discussion and further work

In this paper we have presented very promising results of a perception system for efficient, accurate and repeatable trajectory detection for vehicle guidance. Several experiments have been carried out with different sets (> 150 samples of the entire test lane) of real data; the obtained precision error is +/- 5 mm. and +/- 0.87 degrees.

The system is capable to perform real-time and high-accurate tasks. We have also introduced an initial approach for curve anticipation, and the results have shown the flexibility, robustness and efficiency of our perception system. It is possible to use it in more complex control strategies for real-time applications such as the high-accurate automatic control of buses and also to increase the velocity of the vehicle.

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