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## **EXPERIMENTAL EVALUATION OF PERCEPTION AND ACTUATION ARCHITECTURES FOR THE ARTICULATED VEHICLE AUTOMATIC CONTROL**

*Nowadays, with highly developed instrumentation, sensing and actuation technologies it is possible to foresee an important advance in the field of autonomous and semi-autonomous transportation systems. Among the most promising transport infrastructures the articulated bus is an interesting, low cost and friendly option. In this paper an experimental set-up for research on automatic control of articulated bus is presented. Comprised by a mobile platform (the articulated bus) fully instrumented and a ground test area of asphalt roads inside CSIC premises, this experimental facility allows full testing of automatic driving systems. Paper presents obtained experimental results linked to real time testing of proposed control-perception architectures and a human-machine-interface developed to ease progress in control system evaluation.*

**Keywords:** Intelligent Transport Systems, Bus Rapid Transit, autonomous transport systems, vehicle control, perception, human machine interface.

### **1. INTRODUCTION**

The development of automated vehicles has been the subject of important research activities, where control systems play a very relevant role [1]. By other side, the interest of new, safer, more reliable, mass transportation systems is of growing interest, leading to Intelligent Transport Systems (ITS) [2-3]. Control of vehicle dynamics has been increasingly investigated over the last 15-20 years [4-8]. Bus Rapid Transit systems are a promising transportation system that is becoming very popular and their automation is of major relevance [2].

In this paper an experimental set-up for research on automatic control of articulated bus is presented. The aim of this set-up is to allow full experimentation in real conditions for testing technological developments, perception approaches and control algorithms. Experimental set-up consists in a mobile platform (the bus, a Volvo BM10) fully instrumented and a ground test area composed of asphalt roads inside CSIC premises [9].

### **2. EXPERIMENTAL SET-UP OVERVIEW**

The purpose of the experimental set-up presented in this paper is to provide 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 (Arganda del Rey, Madrid). There are a number of applied research projects involving several industrial companies, engaged in transport issues, which are being realized in co-operation with the IAI-CSIC taking advantage of such facilities. In particular, this paper presents some results related to the feasibility studies undertaken on automatic control of large dimension vehicles. 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.

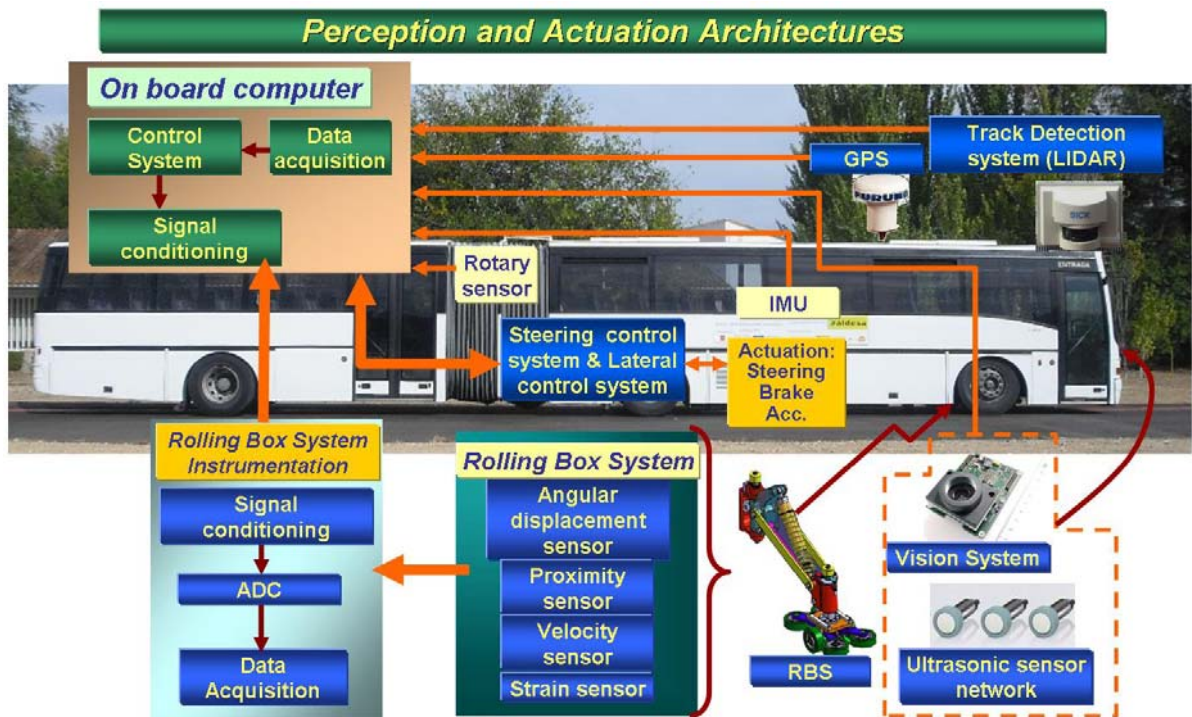


Figure 1. Proposed architecture for perception, actuation and control for the automation of articulated bus.

To evaluate different sensing, communication and actuation systems for automatic control of articulated bus, the mobile platform is complemented with a ground facility where infrastructure modifications could be made to investigate new transport systems or concepts [9] (Figure 2).



Figure 2. Partial and panoramic views of the test lane facility (385

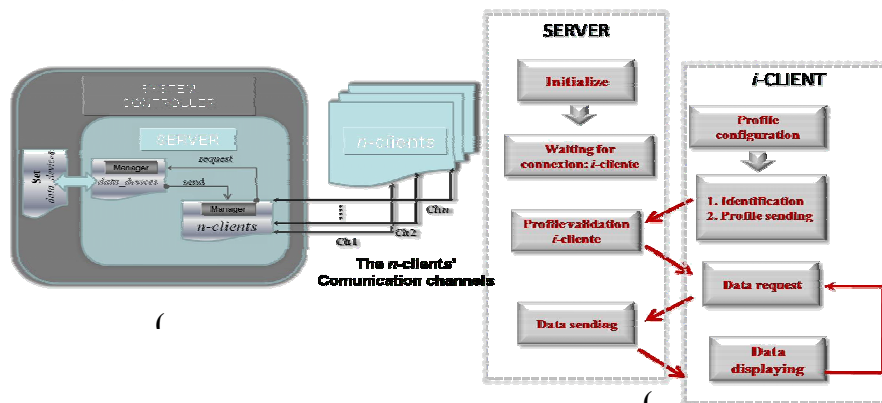
### 3. HUMAN-MACHINE INTERFACE

Proper research on automatic bus control requires deploying multiple sensors and actuators so that they will be used for both monitoring and control. Furthermore, a control system of this kind involves a lot of variables to analyse and to monitor during the testing period of the system and also during the various stages of implementation and demonstration. Therefore, it is of considerable importance to organize a robust observation and acquisition information architecture to gather the sensor signals that are set in the system. The analysis and interpretation of these variables will benefit the design and the comparison of the different architectures and control strategies to be implemented. Additionally, experimentation with

transport systems of large dimensions requires special care for safety, and this involves knowing the state of the vehicle at all times. This information must be known to both the people who go on board the vehicle, and to those working at different points of the test bed facilities.

In this section the main characteristics of a Human-Machine Interface developed to operate during the research on automatic control of articulated bus will be described. At this moment the important consideration for HMI design can be gathered as the targeted user group, in this case comprised by the researchers involved in the study of this project. The environmental constraints are considered a key point for designing this HMI. First, the mobile system is a long vehicle, with multiple variables, working in tough conditions under real time operation system. Because it must cover large displacements, the operator's safety (and comfort whenever possible) is a high priority. The HMI must display comprehensible information and significant information, and the real-time requirements must be satisfied. The main purpose of the HMI is to establish friendly, remote and intuitive communications between the vehicle and the people who operates it, and it also includes an adaptable and open configuration. Thus, the HMI contains the following properties:

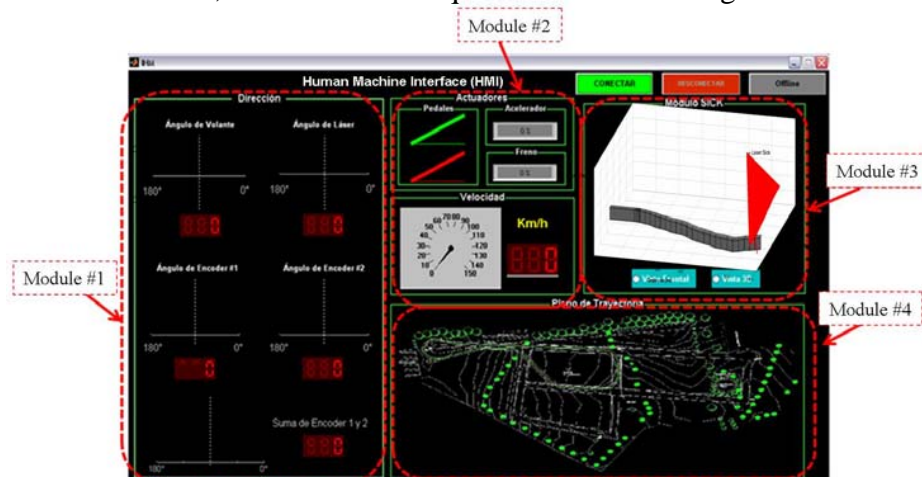
- Multiple sensors and variables can be visualized; two and tree dimensions are considered for some sensors.
- Real-time visualization of the information.
- Multiple and simultaneous clients connexion can be accepted.
- Adaptable according to the requirements/ configuration of every client.
- Data storage for every testing session.
- Old session can be visualized – offline mode.
- TCP/IP communication protocol has been used to communicate the vehicle and the users (researchers).



**Figure 3.** (a) General diagram of the remote system communication; (b) Block diagram of communication sequence between server & *i*-client.

The HRI client-server architecture is based on a server running onboard the vehicle, operated on the RTOS named QNX® [10] and the client can run in any PC with OS Windows Xp or Vista; it has been developed using Matlab [11]. A simultaneous connection of several clients, from  $i=1 \dots n$ , is possible, where each client is denoted as *i*-client. Figure 3a shows the general diagram of the remote system communication between the server and the *n*-clients. The server consist of a Clients Manager, its purpose is to create and to control the communications channels with every connected *i*-client. It also has to handle the clients' requests considering the clients' initial configuration. In order to communicate the server and the main controller, an interface has been created called *data\_devices Manager*, which is charge of acquiring the information of the active devices and variables of the system.

The *i*-client consists of a graphical interface and a *Configuration\_Profile Manager*. The graphical environment is intended to display the multiple variables of the vehicle; the variables are classified and positioned in four groups or modules (See Figure 4). The module #1 displays the variables strongly associated to the steering control: the steering wheel position (angle), the deviation angle detected by the range sensor and the position sensors (encoders) of the articulation of the RBS. The variables related to vehicle movement as the velocity and the interpretation of the brake and accelerator pedals are displayed in the module #2. The depiction of the information acquired by the range sensor, whether it is displaying the data in 2D or 3D is presented in the module #3. Finally, the module #4 display the trajectory plane if the test lane. In addition, the module #4 shows a cursor indicating the position of the articulated bus, in real time, during the execution of a task. The *Configuration\_Profile Manager* is in charge to supervise execution of the *i*-client, according to user's requirements. The operation mode whether it be online or offline and the correct displaying and storage of the chosen devices, this initial configuration is performed through a configuration window (See Figure 4). The remote communication begins by means of any *i*-client. The first action is the *i*-client identification, then it sends its initial configuration profile, previously established where the user chooses the variables of the system that the user wants to monitor, such as: power steering, laser angular position and data, angular position of the RBS, bus velocity, accelerator driver, brake driver, GPS, IMU. Once the configuration has been confirmed, the server starts the data sending procedure. The process will be performed until one of the linked part breaks the connexion; the connexion sequence is shown in Figure 3b.



**Figure 4.** HRI graphical environment with range sensor 3D visualization (module #3).

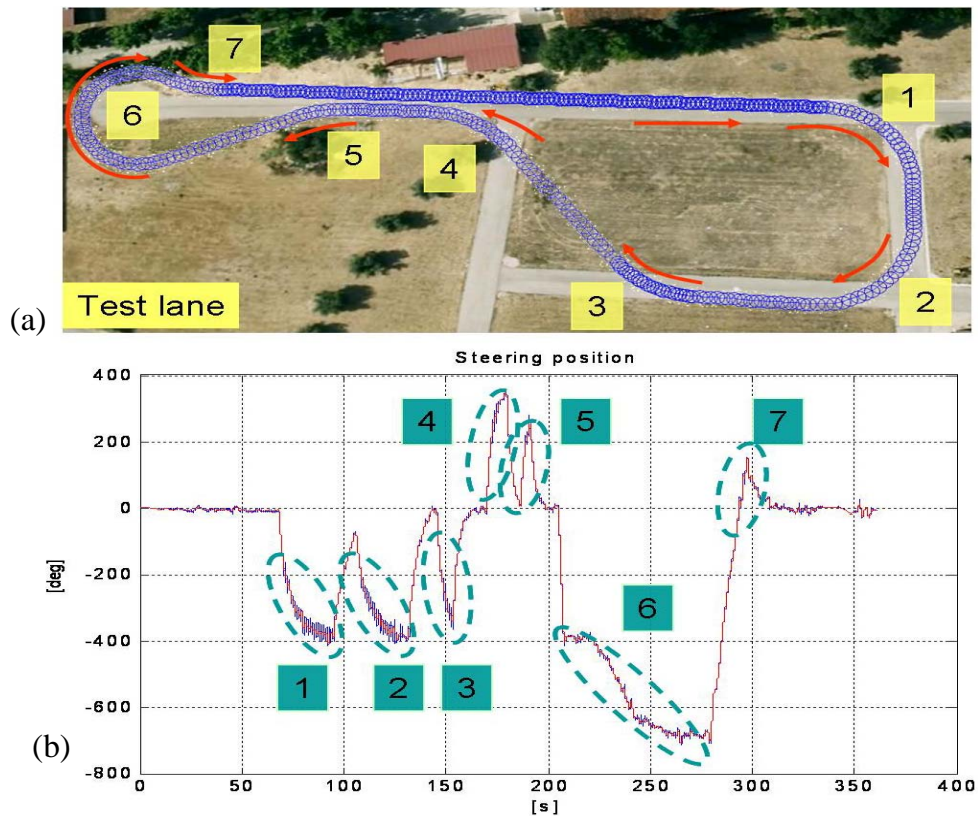
Due to the communication system is designed to operate with multiple and simultaneous clients/users, the server performance is not affected when an already *i*-client is disconnected or a new *i*-client is connected. The *Clients Manager* creates independent channel for every *i*-client and when the server is disconnect it sends a shutting down signal to all connected clients.

#### 4. EXPERIMENTAL RESULTS

Many experiments have been performed within this experimental test area. Figure 5 illustrates automatic control of the articulated bus following a required trajectory. Steering wheel angular rotation experimental data is shown in correlation with real trajectory. In this way, many lateral control algorithms were compared using this experimental platform, where clear and reliable external references and instrumentation have demonstrated to be very useful.



Results presented in Figure 5b, shows the capability of the automatic control to follow the test lane.



**Figure 5.** (a) New test lane for buses over the old experimental road at IAI-CSIC; (b) Steering wheel position (angle) during an experiment performed on the new test lane.

During follow-up of curves, the control strategy makes the central axis of the bus conform to the curvature of the trajectory. Because the radii of curvature of the test lane are significantly small (in some cases less than 12 m), the experiments have been performed at low speed. Kalman filtering techniques were applied to assure data reliability.

The vision-laser sensor is used to anticipate the position of the test lane during a trajectory. Depending on the speed of the bus and the resolution of the laser sensor, it could set its angular limits so it can get measurements within a specific range.

Additionally, the laser sensor detects the driftage of the test lane and the inclination of the surface, providing adequate information to the control system. On the other hand, it can be used to detect, very easily, obstacles located in front of the bus within the range of the laser sensor.

## 5. CONCLUSIONS

In this paper an experimental platform for research on automatic control of articulated bus has been presented. Apart from the mobile system (a Volvo B10M) fully instrumented, a ground infrastructure was also introduced. To help and ease development, a HMI was realised, to monitor all the variables of interest. Experimental results regarding lateral control of articulated bus were offered. The lateral control is improved with the introduction of Kalman Filter in the control algorithm.

## 6. ACKNOWLEDGEMENTS

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