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BLUETOOTH-NETWORKED TRAJECTORY CONTROL OF AUTONOMOUS VEHICLES

A. Valera, M. Weiss, M. Vallés, J.L. Díez

Department of Systems Engineering and Control
Universidad Politécnica de Valencia, Valencia, Spain.
P.O.Box 22012 E-46071. Tel. 34-96-3879570 Fax 34-96-3879579
e-mail: {giuprog, mvalles, jldiez} @isa.upv.es, martin.weiss2@de.bosch.com

Abstract: Nowadays, increasing the efficiency of technical processes is center of investigation in many fields of engineering as, in this way, the use of raw materials and costs can be dropped. Here, control engineering plays an important role to achieve these objectives by stabilizing, speeding up the desired processes and making them more precise.

In control engineering, practical work is of high importance. However, the cost of experimental platforms uses to be very high. So, it is quite difficult to have a reduced control engineers per platforms ratio.

First, this work will present a low-cost autonomous vehicle laboratory experiment. The laboratory is based on LEGO Minsdstorms vehicles equipped with a new communications system based on a Bluetooth-to-infrared adaptor. After that, the paper will deal with the trajectory control of these vehicles.

Keywords: Control applications, computer control, robot control, Kalman filter, control architecture

1 Introduction

In control engineering, practical work is of high importance to understand the complex coherences between system-structure, controller types and technical realization problems as filtering, discretization and delays performed (Valera et al, 2005a).

There are a lot of companies selling complete laboratory experiments of all thinkable types and many universities build them themselves. However these experiments use to be quite expensive and, so, the students per experiment ratio uses to be high.

However, now it is possible to acquire several cheap platforms based on robotics (ActivMedia's Pionner robot, MIT's HandyBoard and Cricket controller cards, The LEGO Group's LEGO Mindstorms, etc.). These platforms usually consist of controllers, electronic sensors, low-cost mechanical parts and/or small robots (Weinberg, Yu, 2003). They do not provide the same precision than industrial robots, but they are sufficient for educational purposes.

Here, LEGO-Mindstorms can be a cheap alternative with approximately 200 Euros for one invention set. It is also very flexible with more than 700 different parts and offers a great variety of possible experiments. It includes a microprocessor, called RCX, with 3 analog inputs and outputs, which can be easily programmed by the delivered graphical software ROBOLAB or one of the many cross-compilers which allow to write programs in common languages like C/C++, BASIC or JAVA (Gawthrop and McGookin, 2004), (Baum et al, 2000).

Furthermore, it provides motors (actuators) and different types of sensors: light sensors, contact sensors, rotation sensors and temperature sensors.

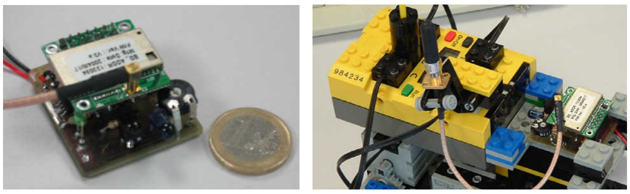
This paper will deal with the control of autonomous vehicles, and more specifically with Bluetooth communications, velocity and trajectory control of autonomous vehicles, image processing and control applications.

2 Low-Cost Robot Mobile Control Architecture

LEGO Mindstorms system includes an infrared (IR) tower for communication between PC and RCXs. This IR tower allows downloading into RCXs the operating system and the programs to be run.

Although IRs are good for short distances and specific communications, they have some limitations related to the maximum angle between devices and maximum distance. This leads to some problems when IR is used for devices (mobile robots) with freedom of movement, where distances are variable and/or visual contact is missed, or in the case that a communication system among different RCXs is required.

In order to overcome IR limitations a radio-frequency solution has been developed for the LEGO system (Figure 1a). Bluetooth© has been chosen given the simple solutions that provides for interferences, bands to be used, protocols, ranges, compatibilities, etc. The developed communications system is a Bluetooth emitter-receiver to be situated in front of the RCX as shown in Figure 1b. In this way, after and adaptation of IR serial signal to logical levels of Bluetooth chip, the communication between RCXs and PC or among RCXs can be performed (Valera et al, 2005b).



a) b)

Figure 1: Developed communications system. It includes an IR emitter and receiver that communicate with RCX.

Figure 2 shows the control hardware architecture proposed for this work. The mobile robots are based on LEGO systems equipped with the new Bluetooth based communication system.

In the control architecture there is a computer that will provide the references for the mobile robots. Depending on the kind of controller, the references can be the desired trajectory, the control actions for its actuators, etc. Another computer in the laboratory is equipped by a camera that will indicate the real position of the mobile robots.

This control architecture allows a great variety of activities. The simplest tasks can be the development of pre-programmed movements. In these cases there is only one basic open-loop controller running on the LEGO RCX. Using the same principle, but including the error signals, close-loop controllers (a kind of P/PID) can be realized as a next step.

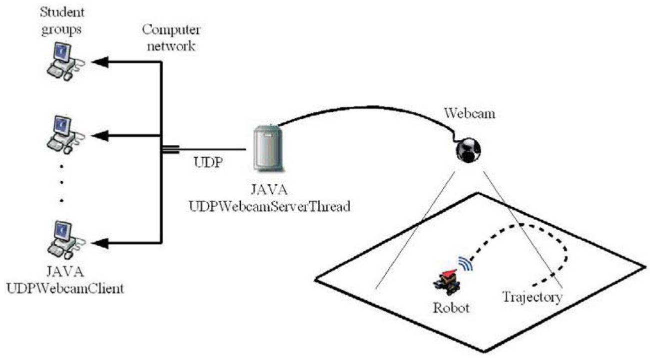


Figure 2: Control hardware architecture

Additional tasks can deal with, for example, dynamic collision avoidance, time-critical image processing, path search, etc. These are more complicated tasks which require practical algorithms for detection of robot and obstacles, and alternative methods for path search.

3 Controller And Observer Design

Using the kinetic model to control a vehicle is a very common method. Thus the control problem is separated in two levels, a kinematic and a dynamic part. This corresponds to a cascade control, where the kinematic level represents the outer loop and the dynamic part the inner loop. Often for the kinematic controller a more complex controller type can be found whereas the much faster controller of the dynamics is a basic PI or PID controller.

The same principle also is used in this application, with the difference that inner and outer controller are connected via network and Bluetooth. The inner loop is implemented directly on the RCX by two PID controllers that are used to control the track speeds using the velocity signal provided by encoders on both axes. The outer loop consist of a feedback linearization of the non-linear robot state.

In order to obtain the outer controller, the system state (position X-Y) and encoder values are not sufficient. Further states are needed, especially the vehicles orientation (heading) and linear and angular velocity.

Since these values can't be measured directly, an observer was designed to estimate them. Regarding the noise of the sensors and the relatively simple system structure, the best choice appears to be an Extended Kalman Filter (http://www.cs.unc.edu/~welch/kalman/).

Velocity Controller

To establish the inner control loop for the track velocities, a discrete PID has been used. In order to analyze local system dynamics a typical method is to measure the system's step response. The form of the step response often gives important insight in system structure and dynamic order and allows to estimate dynamic parameters.