

# REAL ROBOT REMOTE CONTROL VERSUS SIMULATIONS

**Dorin Popescu\*, Dan Selisteanu\*\***

*\*University of Applied Sciences FH Ravensburg-Weingarten  
Doggenriedstrasse, D-88250, Weingarten, Germany*

*\*\*University of Craiova, Faculty of Automation, Computers and Electronics  
5 Lapus Street, 1100, Craiova, Romania  
dansel@automation.ucv.ro*

**Abstract:** This paper presents some remote experiments with a real mobile robot related to PID controller design, simulations on mathematical model of the mobile robot and comparisons between both types of experiments. The goal of this work was to achieve a good training of the students in the field of mobile robots by combining the real robot experiments with simulations. The didactical mobile robot is remote operated via Internet to test different PID controllers. The real infrastructure allows open-loop and closed-loop configurations, position or speed feedback control.

**Key words:** mobile robot, PID controller, remote experiment, teaching techniques.

## 1. INTRODUCTION

The robotics teaching material can be classified as (Casals et. al., 2002): simulators, self-made robots, real robots, on-line robots. Of course, it is essential to apply the theory on real robots, but in most cases the use of this method is expensive. For this reason, the use of simulators is common and it constitutes an alternative to real robots.

Another possibility is to use on-line robots, which offer a good platform to share experimentation through Internet. The progress in modern Multimedia and Telematics technologies offers good potential for presenting in tele-education theory and practical experiments in an interesting and economical way (de Lafontaine, 2002), (Dormido, 2001), (Schilling, and Roth, 2001). The high cost necessary to implement experiments (for didactical purposes) with manipulators and robots led to the development efforts for tele-operated facilities where the physical robot, sensors, and operating environment can be remotely controlled via the Internet. Tele-operated systems have gained considerable attention in recent years due to new potential applications, such as remote production monitoring, remote exploration, manipulation in inhospitable environments, tele-surgery, and tele-teaching.

In order to achieve a good practical training of the students in the field of robotics it is very interesting and useful to combine the real robot experiments with simulation (Popescu et. al, 2002), (Selisteanu et. al, 2003). One vital aspect of robotics education is the practical work necessary to give students a taste of real situations. For the students, the idea is to be able to perform real experiments, in real time, on real equipment, but over the Internet. So, the students can compare the simulation on the mathematical model of the robot with the behaviour of the real robot.

This contribution is based on the experience of the University of Applied Sciences Ravensburg-Weingarten from major national and international virtual laboratory projects (Popescu and Schilling, 2003), (Schilling, 2001), (Schilling et. al., 2002) and cooperation with Romanian researchers.

There are two criteria that allow establishment of a clear classification of the experimentation environments from the point of view of student use: the nature of the system (virtual or real) and the way of accessing the resources for experimental purposes (local or remote access). Our experimentation environment represents a real system with remote access. It represents access to a real equipment laboratory through the Internet. The user operates and controls, in a remote way, a real system through an experimentation interface.

The paper is organized as follows. Section 2 gives a short description of the real mobile robot TOM (tele-operated machine) used in remote experiments and presents the procedure followed by the students in order to obtain the mathematical model of this mobile robot. Section 3 analyses a simple PID control design procedure based on the robot model and presents the simulations, which are prepared in Matlab/Simulink environment. Section 4 widely examines the mobile robot remote experiments and presents the advantages of this approach. In this section, the PID parameters obtained from the previous design procedure are tested on the real robot. The resulting performances are compared with those obtained from simulations. Finally, in Section 5 concluding remarks are collected.

## 2. THE REAL MOBILE ROBOT AND ITS MATHEMATICAL MODEL

TOM (tele-operated machine), presented in figure 1, is a didactical mobile robot tele-operated via the Internet to test different PID controllers. A web-cam enables the user to see the robot's movements in real-time while a Java applet interface is used to change data and commands with the TOM server. The commands from the server to the micro-controller are transmitted through asynchronous serial RS-232 link with a custom transmission protocol. The micro-controller used to control the sensors and actuators is a 16-bit Phytex miniModule167.

The mobile robot is a differential drive mobile robot. TOM has the two motor-driven wheels. The mobile robot is equipped with additional wheels that provide support but do not contribute to either steering or propulsion. The two motors are integrated DC gear-motors Maxon A-MAX22 with digital dual-channel encoders HEDS5540. The gearbox has a ratio of 84 and the encoder is 100CPR. This gives us 8400 encoder pulses per wheel turn.

Tele-operation of TOM really allows users to experiment independently of time and location because it is possible to experiment from any computer connected to the Internet.

The remote user is connected by Internet to a dedicated web server that interacts with the computers of the laboratory used for controlling and monitoring the mobile robot.

The real mobile robot and its mathematical model are used for training of the students in the fields of mobile robots and control theory.

The students' tasks are: to obtain the mathematical model of the mobile robot, to design the PID controller, to simulate the open-loop and closed-loop behaviour of the robot model, to achieve remote experiments with TOM through Internet (using the designed PID control) and to compare the results of the simulations and of the real experiments.

For the system modelling experiment the student receives:

- robot description

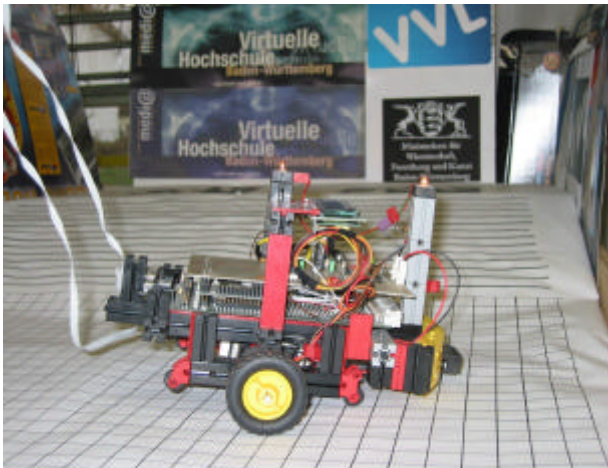


Fig. 1. TOM

- system components parameter values
- basic dynamics equation for each component

In the process of modelling, the students have to:

- define some assumptions for the model
- calculate the transfer function of each component
- draw the block diagrams
- find the open-loop transfer function
- find poles and zeroes and evaluate the stability of the system in open-loop
- obtain a simplified linear model of the mobile robot, which can be used for control design
- plot the step response and evaluate the time response of the system

Some of the assumptions that can be taking into consideration by the students are:

- Motors have identical electrical and mechanical properties
- Motors are operated in the linear region, not in saturation
- The Coulomb friction on supporting rollers is neglected
- Frictions in gearbox are neglected
- Wheels always keep traction, they don't slip on surface
- Rubber driving wheels keep constant shape, are not deforming in operation
- Wheels and front roller always keep contact with the surface
- The operating surface is plane and horizontal
- Initial conditions are null (initial speed and position is 0)
- Calculation and processing delay do not influence the controller in any way

The next step consists in defining four system blocks in the mobile robot system:

Actuators:	dynamics of the DC-motors <sup>12</sup> [V]
Robot system:	dynamics of the robot and wheels
Sensors:	dynamics of the encoders
Amplifiers:	dynamics of the amplifiers

To obtain a linear model of the mobile robot, a four step systematic procedure has to be applied by the students:

1. Sorting the dynamic equation describing the system
2. Transform these equations into the Laplace domain
3. Drawing the block diagram
4. Calculating the transfer function

This procedure will be applied to each system block and then to the motor-wheel system itself.

The expanded open-loop transfer functions (without the controller) for position and speed look like the following equations:

$$\begin{aligned}
 H_{OP-POS}(s) &= \frac{P_{meas}(s)}{U(s)} = \\
 &= \frac{K_{amp} K_a K_{sen}}{J^* L s^3 + (R_a J^* + L B_m) s^2 + (R_a B_m + K_a K_e) s}
 \end{aligned} \tag{1}$$

$$H_{OP-SPD}(s) = \frac{V_{meas}(s)}{U(s)} = \frac{K_{amp}K_aK_{sen}}{J^*Ls^2 + (R_aJ^* + LB_m)s + (R_aB_m + K_aK_e)} \quad (2)$$

where:

$B_m$  - rotor dynamic friction constant

$L$  - DC-motor coil inductance

$R_a$  - DC-motor armature resistance

$K_a$  - DC-motor electro-mechanical constant

$K_e$  - DC-motor electro-motive feedback constant

$J^*$  - moment of inertia that depends on rotor inertia  $J_m$ ,

wheel moment of inertia  $J_{wheel}$ , robot total mass  $m_{robot}$ ,

wheel radius  $r_{wheel}$

$K_{sen}$  - sensor constant

$K_{amp}$  - amplifier constant

$P_{meas}$  - the measured position

$V_{meas}$  - the measured speed

$U$  - the command voltage

The students, using the real parameters values of TOM, after some straightforward calculations, will obtain finally the following transfer functions:

$$H_{OP-POS}(s) = \frac{655200}{s^3 + 15280s^2 + 655200s}$$

$$H_{OP-SPD}(s) = \frac{655200}{s^2 + 15280s + 655200}$$

By studying the above transfer functions, the students can obtain the step responses, the pole-zero map etc., and can analyse the stability and the dynamic behaviour. For instance, they can notice that the model has a real dominant pole at -43 and a pole at -15237 (from the mechanical, respectively the electrical time constants). If the negligible pole is removed, simplified transfer functions can be obtained:

$$H_{OP-POS}(s) = \frac{43}{s(s+43)} \quad (3)$$

$$H_{OP-SPD}(s) = \frac{43}{s+43} \quad (4)$$

The simplified linear model of the mobile robot can be used by the students in the control design procedure.

### 3. PID CONTROLLER DESIGN AND SIMULATIONS

The simplified robot model is used by the students for open-loop simulation and, more important, for the design of the control law such that the closed-loop system is able to satisfy the imposed performances. One of the simplest but efficient controllers is the PID controller, which is implemented on the real robot TOM. So, it is useful for students to design the PID controller and to use it for both simulation and real experiments.

The control goal, which is necessary to achieve by the students, is to design a PID control law such that the closed-loop system (robot plus controller) assures some imposed performances, related for example to the overshoot  $\sigma$  and the settling time  $t_r$ .

The well-known PID control law is described by the transfer function

$$H_C(s) = K_P + K_I \frac{1}{s} + K_D s \quad (5)$$

with  $K_P$ ,  $K_I$ ,  $K_D$  the proportional, integral and derivative parameters.

The students will calculate the PID parameters, taking as initial design data the imposed performances, the controller transfer function (5) and the mobile robot transfer function (3) or (4), using a classical feedback control design procedure, for example the poles-zeros allocation.

For instance, we suppose that the control goal is the position control and the imposed performances are  $\sigma\% < 3\%$  and  $t_r < 3$  sec. The students can choose a two-order closed-loop transfer function as a model:

$$H_{CL-POS}(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \quad (6)$$

where  $\omega_n$  is the fundamental frequency and  $\zeta$  is the relative damping coefficient.

Through a poles-zeros technique, the students will obtain the values of the two parameters  $\omega_n$ ,  $\zeta$  such that the imposed performances are satisfied and the PID control transfer function is simple and physically realisable. For example,  $\zeta = 0.8$  assures the desired overshoot, and  $\omega_n = 26.875$  allows a settling time below the imposed one. Furthermore, after straightforward calculation, the obtained PID controller is a simple proportional controller:

$$H_{CL-POS}(s) = \frac{H_C(s)H_{OP-POS}(s)}{1 + H_C(s)H_{OP-POS}(s)} \Rightarrow$$

$$H_C(s) = \frac{H_{CL-POS}(s)}{1 - H_{CL-POS}(s)} \cdot \frac{1}{H_{OP-POS}(s)} = 16.79 = K_P$$

With this proportional controller, the students will simulate the behaviour of the closed-loop system, using Matlab/Simulink. The step response of the closed-loop system (for a step reference signal of 100 mm value) is represented in figure 2. In figure 3 is presented a zoom that allows a better evaluation of the overshoot. It can be

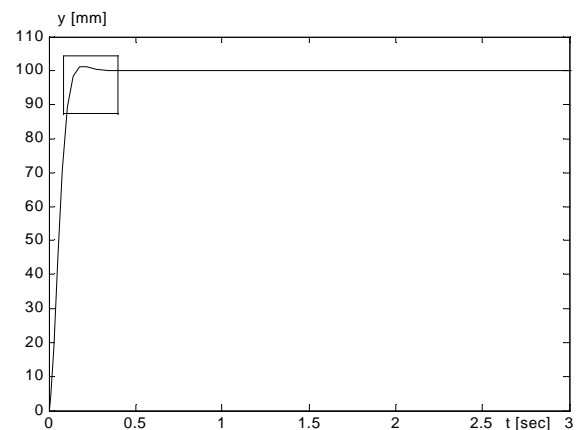


Fig. 2

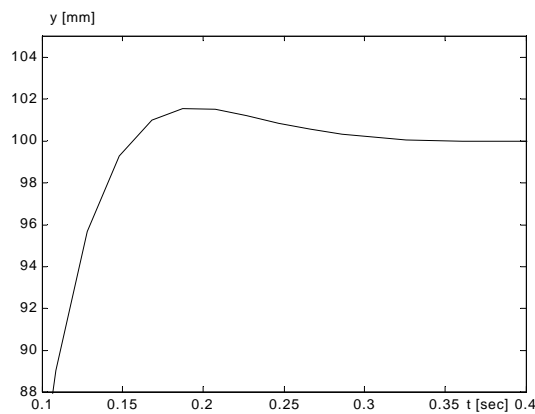


Fig. 3

seen from these pictures that the response of the simulated controlled robot is very good (precision, overshoot, settling time). Of course, the real experiments achieved by the students will prove that this ideal behaviour cannot be obtained because the approximations considered in the modelling and design processes.

In order to test the model of the robot, which is obtained following the procedure described in the previous section, the students can design a range of PID controllers by imposing different performances and using various control design techniques. The influence of

each PID parameter on the behaviour of the closed-loop system can be analyzed, such that the students will understand the effects of these parameters on system response. The speed control can be considered as control task. The simulated behaviours will be compared with the real remote experiments.

#### 4. REAL ROBOT REMOTE EXPERIMENTS

The general purposes of remote experiments with the mobile robot TOM are:

- to introduce the students to the background of DC motors and PWM;
- to use a classical system dynamic modelling procedure;
- to introduce students to design of a PID controller for a mobile robot;
- to familiarize students with the use of experimental PID tuning methods.

The remote experiments have been adapted to provide a student self-study access via Internet. The components include:

- a tutorial covering the background theory for the experiment
- interactive questions/answers and exercises, providing the student feedback about his learning

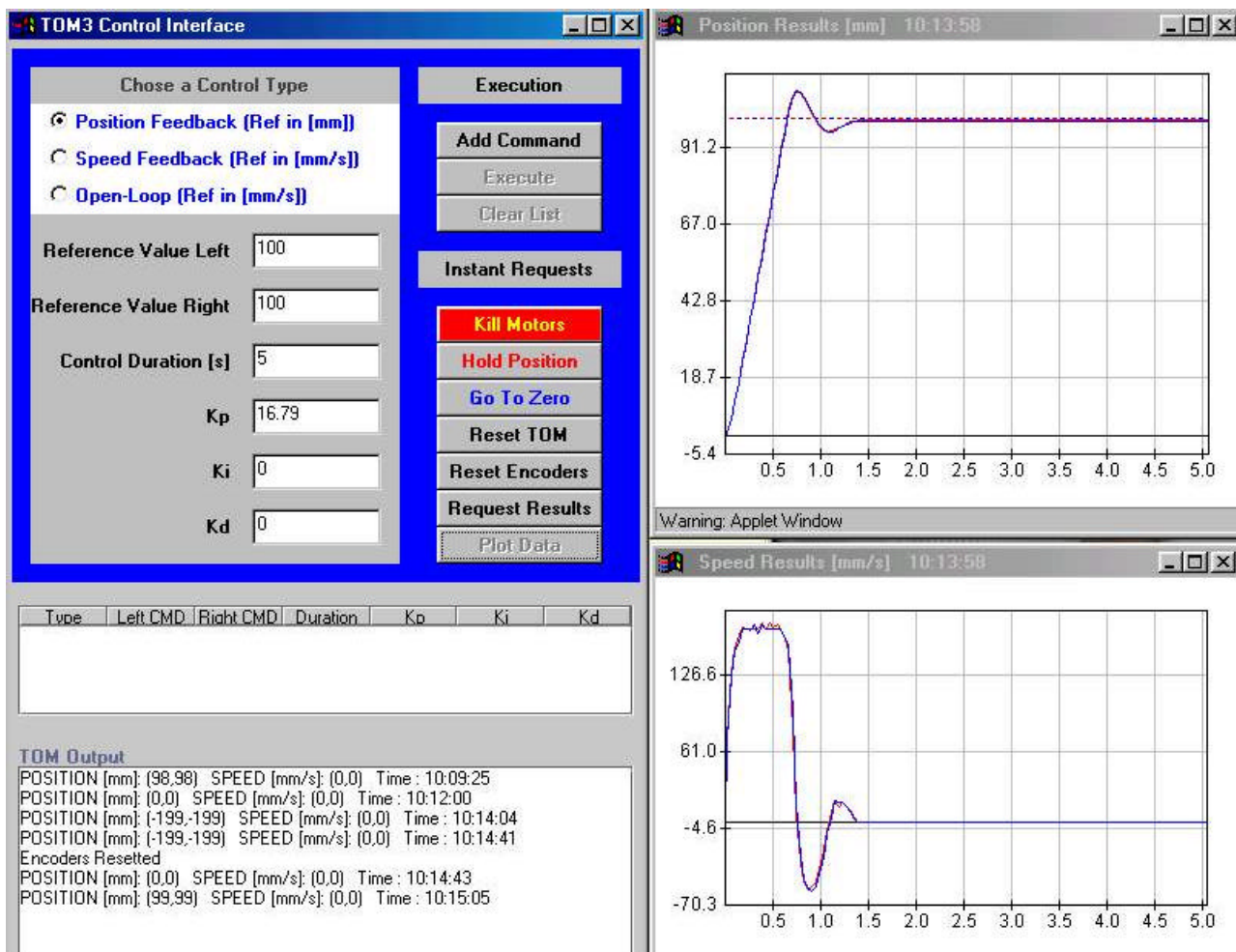


Fig. 4



achievements

- Internet access to real hardware to deal with real world applications, including the inherent noise and disturbance effects.

The user is guided from didactical texts with integrated feedback questions, through simulations, toward experiments with the remote real mobile robot. Some didactical chapters about DC motors, dynamic modelling, PID controller, and experimental tuning are provided based on references such as (Dudek and Jenkin, 2000), (De Wit, et. al., 1995), (Ogata, 1997). Each of them is followed by test questions. The users can only progress in the learning process after they have answered all questions correctly. In the end, a real mobile robot will be tele-controlled by the user's PID controller to demonstrate the effects of position or speed controlling. The first step of a remote experiment achieved by the students is to set the PID controller coefficients (using the interface - see the left side of figure 4) and to execute closed-loop commands. A web-cam window allows users to see the movements of the mobile robot in almost real-time.

The second step consists in observing the dynamic behaviour of the controlled mobile robot through plotting and analyzing the responses. For example, if the students use the proportional controller obtained as in the previous section (using the simplified model of the mobile robot), the response for a 100 mm position reference is like in the up-right side of figure 4 (the speed response is plotted in the down-right side of figure 4).

The third step of this experiment procedure is to compare the real results with the theoretical responses obtained through simulation.

The students will comment the differences between the two approaches and will try to improve the performances of the closed-loop system. For example, from figure 4 it can be notice that the overshoot is quite big. By setting a derivative component in addition to the P controller, the

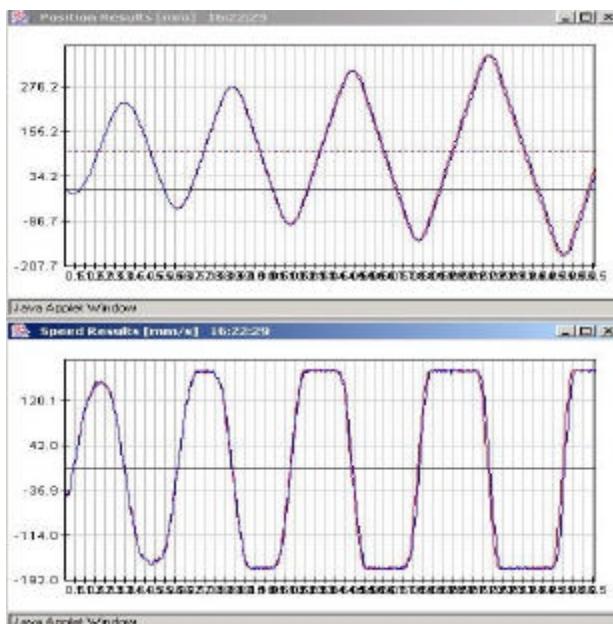


Fig. 6

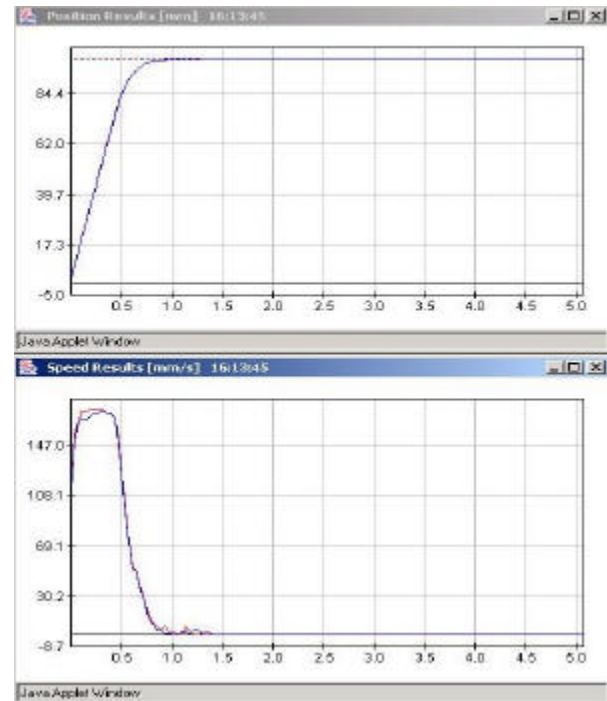


Fig. 5

overshoot can be eliminated (see the figure 5).

Achieving various remote experiments, the students can understand what saturation, overshoot, steady-state error, settling time mean.

Another possible situation, which can appear for a wrong controller design, is the instability of the closed-loop system (see the figure 6).

The TOM interface facilitates control experiments for students by first modelling a complex dynamic system and then designing a PID controller to provide stability and performance. This experiment bench would bring the student in contact with non-linear behaviours that makes a classic linear model not quite valid to precisely predict the system response. Therefore, students learn to deal with such non-linear phenomenon and may try to find more proper ways to come to an efficient PID controller, or they can use the experimental tuning approach.

The remote mobile robot experiments belong to tele-education technologies, which implement a distributed education environment independent of time, space, and individuals.

Some advantages of the mobile robot tele-education are:

- self learning
- facilities for studying independently of both time and location
- appropriateness of the subject to remote operation
- better presentation of complex material by using multimedia elements
- testing robot with regard to the accuracy in positioning
- experimental PID tuning
- position and speed feedback PID control
- remote surveillance (through web-cam & chat server)
- advanced training system

- tele-education permits continuing education with minimum costs.

Some remarks related to our experimentation environment are:

- access to our remote environment was carried out exclusively via the Internet. A web navigator is the only necessary software tool that students need when undertaking a practical experiment.
- our remote mobile robot promotes students' interest and motivation when they obtain real and coherent responses. The system reacts in almost real time to any action from the student.
- no time restriction. The only limitation is that which is created another user when he occupies the mobile robot or when maintenance work is being done.

## 5. CONCLUSIONS

The purpose of this work was to perform a good training of the students in the field of mobile robots. The use of simulations can provide the basics in the field of modelling and control, is not expensive, but has some limitations due to the imprecise knowledge of parameters and structure of the model. On another hand, a vital aspect of robotics education is the practical work necessary to give students a taste of real situations. An undeniable problem is the cost of the real robots, so if they are not accessible in the own laboratory, a viable solution is to perform real experiments, in real time, on real robots, but over the Internet. An appropriate teaching approach is to use both techniques: simulations followed by real robot experiments, or remote experiments through Internet. So, the students can compare the simulation on the mathematical model of the robot with the behaviour of the real robot.

Tele-education experiments with remote mobile robots are the contribution from the University of Applied Sciences FH Ravensburg-Weingarten to the more extensive virtual laboratory addressing automation technology in the project VVL of 6 cooperating universities in Baden-Württemberg.

Mobile robots provide an excellent test-bed for modelling of vehicle kinematics and dynamics, for testing of the PID controllers.

This paper presents some remote experiments with a real mobile robot related to PID controller design, simulations on mathematical model of the mobile robot and comparisons between both types of experiments.

The Internet represents a major opportunity for robotics education: the development of remote laboratories where students can gain practical experience by efficient use of hardware resources. Equipment will be made available to more students as the time and space constraints normally associated with the traditional laboratory can be reduced.

The advances in computers and those resulting from the society of information provide new means for the improvement of learning technologies. The presented teaching system allows an improvement in robotics education and training. The experiments help students to understand and compare different (real and simulation) modelling and control methods.

## REFERENCES

- Casals A., Aranda J., Fernandez J., Frigola M. (2002). Evaluation of Learning Technologies in Robotics, *IEEE Internat. Conf. on Robotics & Automation ICRA 2002*, TA-11, 11-15 May, Washington, USA.
- de Lafontaine, J., and C.-A. Brunet (eds.) (2002). *Proceedings 2nd International Workshop on Tele-Education in Engineering Using Virtual Laboratories*, Sherbrooke, Canada.
- De Wit, C.C., B. Siciliano and G. Bastin (1995). *Theory of Robot Control*, Springer Verlag.
- Dormido, S. (ed.) (2001). *Internet Based Control Education, Proceedings of the IFAC Workshop on Internet Based Control Education*, Madrid.
- Dudek, G. and M. Jenkin (2000). *Computational Principles of Mobile Robotics*, Cambridge University Press.
- Ogata, K. (1997). *Modern Control Engineering*, 3<sup>rd</sup> edition, Prentice Hall.
- Popescu, D., D. Selisteanu and C. Ionete (2002). Simulated and Practical Exercises for Robotic Structures, *The 3<sup>rd</sup> Intern. Conf. on Information Technology Based Higher Education and Training ITHET 2002*, Budapest, Hungary, July 4-6, pp. 469-474.
- Popescu D. and K. Schilling (2003). Internet based remote experiments with mobile robots for mechatronics education, *Proceedings of 14-th International Conference on Control Systems and Computer Science*, Bucharest, pp. 282-287.
- Schilling, K. (2001). Virtual Laboratories for Mobile Robots, *Proceedings IFAC Workshop on Internet Based Control Education*, Madrid, pp. 115-120.
- Schilling, K. and H. Roth (eds.) (2001). *Telematics Applications in Automation and Robotics*, Pergamon Press.
- Schilling, K., H. Roth and O. Rösch (2002). Mobile Mini-Robots for Engineering Education. *Global Journal of Engineering Education* 6/2002, pp. 79-84.
- Selisteanu, D., D. Popescu and C. Ionete (2003). An interactive teaching system for the modelling and control of robotic structures, *14-th EAEEIE International Conference on Innovations in Education for Electrical and Information Engineering*, Gdansk, Poland, CD-A49.