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An Integrated Internet-based Package for Teaching Motion Control: Content and Testing Results

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Abstract: In this paper, a motion control training package developed at POLITEHNICA University of Bucharest is described. The package is dedicated to automation technicians and students in automatic control. The main objective of the package is to present the basics of motion control in an interactive way using theory, movies, dynamic simulators, games and a remote lab. A statistical study on the educational impact of this innovative training package is demonstrating the positive impact on the learners compared to traditional learning methods.

1. INTRODUCTION

There are numerous applications of advanced educational technologies in control and robotics education (Buiu, 2007). However, there are needed more studies on the impact of new technologies in teaching control engineering compared to traditional classroom education.

There are also a growing number of European research projects dedicated to new educational technologies. One of them is AutoTech (Automation Technicians Vocational Training Repository) which is a Leonardo da Vinci pilot project funded by the European Commission (2004-2007). AutoTech aimed to develop innovative Internet based vocational training packages for automation technicians. Students in automatic control represented a secondary target group. The AutoTech consortium was composed of academic and industrial partners from 5 countries (Norway, Spain, Germany, Romania, and Switzerland). The partners developed several dedicated training packages on: control structures, PID control, PLCs, motion control and fuzzy control. The packages contain a variety of traditional instruments such as theory, simulators, videos, quizzes and include innovative teaching tools such as games, competitions and remote labs. The developed resources were integrated into PIDstop which is a repository of learning resources which are centred on dynamic simulators, attractive graphics and a high degree of user interaction (www.pidstop.com). Feedback from over 2000 users has indicated the enriching and motivational effects of this system (Foss *et al.*, 2006).

In the framework of this project, the Romanian partner, POLITEHNICA University of Bucharest (UPB) has developed a motion control training package which was tested by automation technicians and students following an introductory course in automatic control. It was assumed that the users are familiar with simple notions related to electrical circuits and measurements. References are made to control structures and PID control which are covered in the basic curriculum. The package consists of theoretical parts, demo movies, interactive and dynamic simulators, a remote lab and a motion control related game, finishing with a quiz.

This paper presents the integrated package for teaching motion control and is organized as follows. Section II presents the structure of the training package. Section III presents some results from the evaluation of the whole package, while the last section gives the conclusions and directions for further developments.

2. MOTION CONTROL LEARNING PACKAGE

2.1 Package content

The package was developed primarily for automation technicians and secondly for automatic control students. The structure and flow of information are intuitive and the content was kept enough simple so that the package could be addressed to technicians and students taking introductory courses in automatic control. During the work with this training package the users get familiar with:

- Basics of motion control: definitions, structures and applications (approx. 2 hours);
- DC motors (approx. 6 hours);
- Stepper motors (approx. 3 hours);
- Mobile robots motion control (approx. 3 hours);
- Remote motion control laboratories (approx. 2 hours).

For each module, the user has to start with an introductory part in which relevant theory is presented, mostly as text and diagrams. There are also provided references to books, articles and open sources on the Internet.

Simulators of mathematical models for various motors and related control systems are developed in Easy Java Simulations (Ejs) which is a software tool designed for the creation of computer simulations (Hwang and Esquembre, 2003). Ejs was developed for an Open Source Physics Project at the University of Murcia, Spain (Easy Java Simulations, 2002). Easy Java simulators can be used as independent programs under different operating systems, or be distributed via the internet and run within *html* pages by usual web browsers. Thus the portability of all simulators is assured.

After the five already mentioned modules, there is a game which involves a cruise control system. The package ends with a related quiz.

2.2 Module 1: Introduction to motion control

This module presents definitions and motion control systems structures. Real-world examples from UPB labs (a microcontroller controlling a DC motor, an inverted pendulum, and a 3D crane as in Fig. 1) are presented in 12 demonstrative videos which illustrate the various operating regimes of the respective plants. For example, for the inverted pendulum, the movies present the pendulum swing up and disturbance rejection.

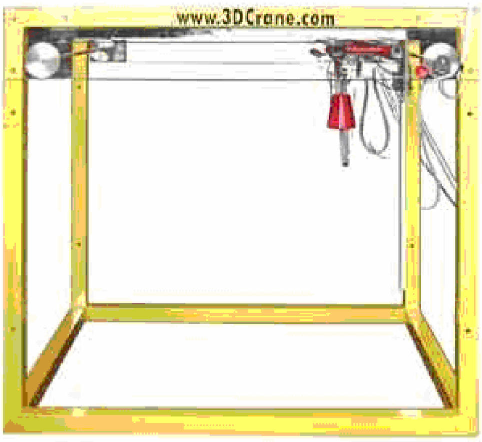

Fig. 1. 3DCrane – a three dimensional positioning system

2.3 Module 2: DC motors

The core of this module is the DC motor which is a fundamental machine in control applications. The theoretical part gives information on how the DC motor works and highlights some of its industrial applications. Seven Easy Java simulators are included in order to present various aspects related to the use of DC motors in motion control applications. The simulators relate to the open-loop and closed-loop simulations of various motors and PID control structures. The user may simulate motors in open-loop structures. There are also simulated PID structures for speed and position control of the microcontroller-based platform, (conventional and cascaded loops), position control of the 3D crane and inverted pendulum swing-up and control. For example, a simple DC motor simulator (Fig. 2) allows the user to modify various parameters (moment of inertia, damping ratio, electromotive force constant, electric resistance, electric inductance, source voltage, friction torque, and the load torque) and to see the corresponding effect in a graphical window (Fig. 3).

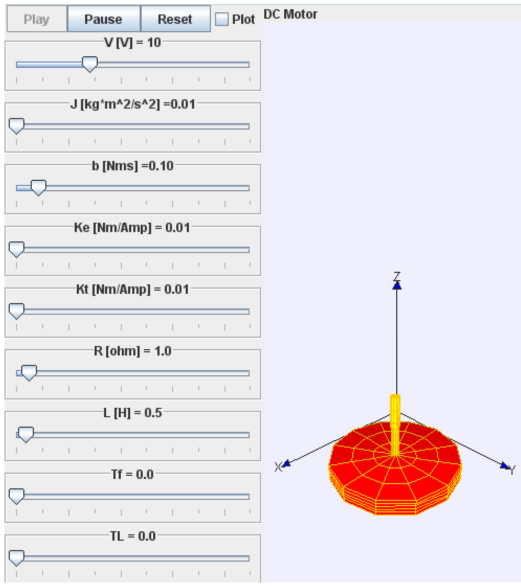

Fig. 2. DC motor simulation – command window

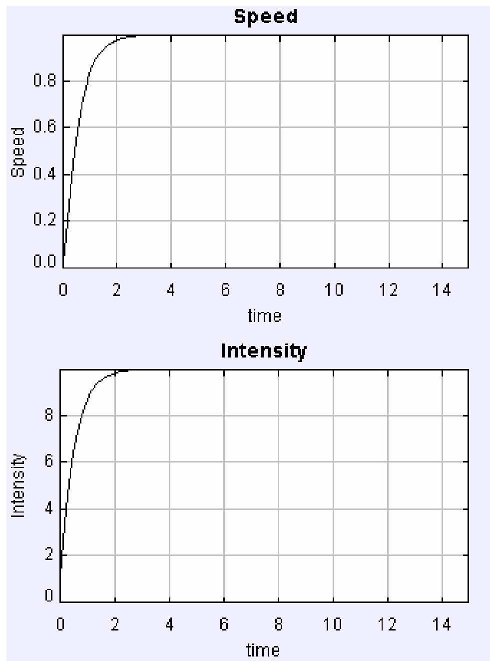

Fig. 3. DC motor simulation – graphical window

2.4 Module 3: Stepper motors

Theory and applications of stepper motors, together with an Easy Java simulator are offered in this module. A simple stepper motor with 4 electromagnets is simulated (Fig. 4 and 5). If the *HalfMode* check box is selected the stepper motor works in half stepping mode (the most common mode) which means that it has a resolution of 45^0 / step. If deselected, the mode is *Full* and the resolution is 90^0/step. The user shall select the number of steps to be performed and the direction of rotation (CW-clockwise or CCW=counter-clockwise). The speed can be adjusted as desired (the lowest speed is 1 step at each second) and this adjustment can be performed also while the simulation is running.

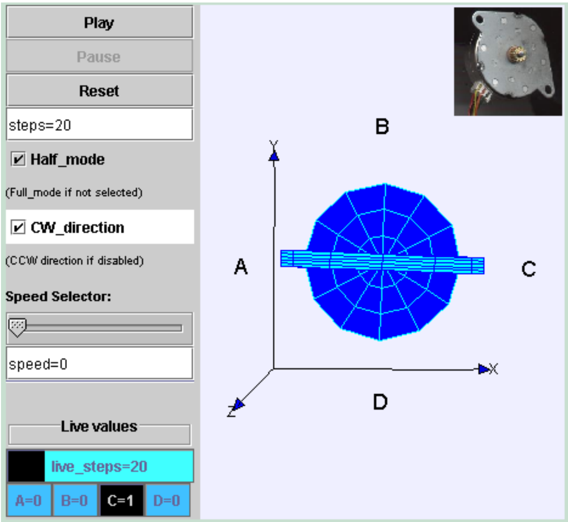

Fig. 4. Simulated stepper motor – command window

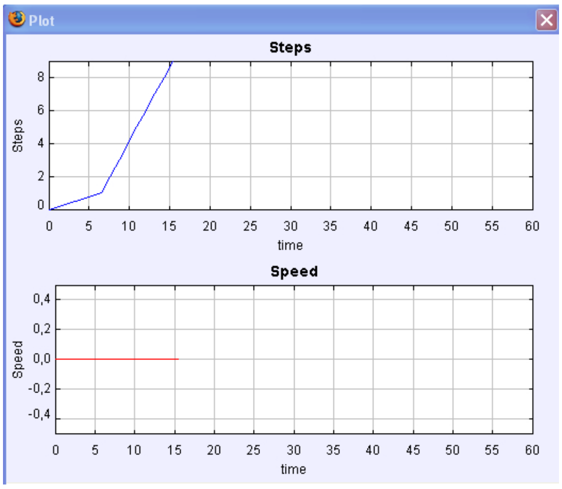

Fig. 5. Simulated stepper motor – graphic output

During the simulation some live values are displayed in the left lower corner of the window (Fig. 4):
- total number of steps performed;
- sequence of commanded electromagnets at each step.

2.5 Module 4: Motion control of a mobile robot

In order to illustrate some of the presented principles and structures, a Khepera mobile robot has been chosen (Fig. 6). The users learn now about the application of PID control structures and algorithms to mobile robotics.

The robot is propelled by two DC motors with an embedded PID speed and position controller. Used in speed mode, the controller has as input the desired speed values for the wheels, and controls the motor to keep these given speeds. The speed modification is made as quick as possible, in an abrupt way. Used in position mode, the controller has as input a target position for each wheel, acceleration and a maximal speed. Using these values, the controller accelerates the wheel until the maximal speed is reached, and decelerates in order to reach the target position.

Fig. 6. Khepera mobile robot

2.6 Module 5: Mobile robot remote motion control

The previous explained principles and structures are applied in this module which deals with a remote lab that was designed to control the motion of a Khepera mobile robot. The implementation of the lab (available online at online.robots.pub.ro) is based on the use of Web services. For example, the user may choose the desired speed for each wheel of the robot and may tune the PID controller (Fig. 7) in order to obtain the desired behaviours. There is a live image with the robot in the lower left corner of the interface. For more information see (Buiu and Moanta, 2007). Using the web-based interface, the user is able to tune the parameters of the PID speed and position controllers while seeing the corresponding remote movements of the robot.

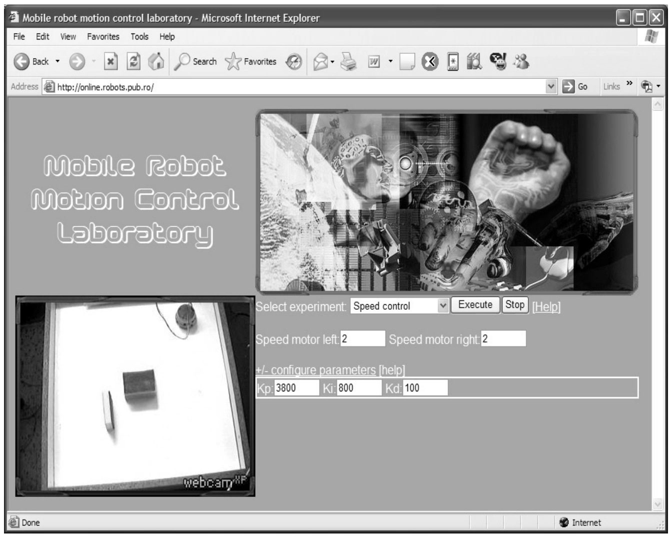

Fig. 7. Mobile robot remote PID speed control

2.7 Motion control game

Various papers study the role and use of games in education (Foss *et al.*, 2006; Haugom *et al.*, 2006). Games have been proven to have an important formative role and in this respect, the motion control package includes a cruise control game. The game was developed in Java and it was designed in order to enrich the learning experience in an attractive way and to stimulate the acquisition of knowledge.

Fig. 8. Cruise control simulator/game

There are two using modes:

A) Simulation mode
In this mode, the user may simulate a common cruise control situation. He/she may accelerate or brake and activate the cruise control system at the desired speed. There is a warning speed and a ticket speed which must be observed. Road angle disturbance may be simulated. The speed controller is a PID one whose parameters may be tuned by the user in order to achieve minimum overshoot or settling time.

B) Game mode
Now, the user must only tune the PID controller to reach and keep the desired speed of 100 km/h as fast as possible. By default, a time limit of 90 seconds is set, and after that time, a score is calculated based on the mean square error between the desired speed and the actual speed. Finally, the score is transferred to a hall of fame where the results of other users may be seen, creating a sense of competition.

2.8 Final quiz

The package ends with a quiz which consists of multiple choice questions, where the users will be able to see their result immediately. There are also textual questions where the users have to write their answer. Some of the questions are directly related to the simulators, so that they have to use the simulators in order to obtain the correct answer.

3. TRAINING PACKAGE EVALUATION FINDINGS

All the AutoTech packages were evaluated by automation technicians, students, and teachers from all the participating countries. The global results and the related comments may be found in (Solbjorg, 2007).

The motion control package was tested by a total number of 42 users (33 students from UPB and 9 automation technicians from AUTOMATICA SA, a Romanian automation company) who had 2 weeks to complete the package. The evaluation questionnaire was prepared by Alforsk, a specialized Norwegian company that was member of the AutoTech consortium. There were 32 questions, organized within 5 categories: learning outcome, content of the package, simulation and games, technical issues and future developments. The questionnaire included some open text questions as well.

The following commentaries are based on some of the evaluation results related to the motion control package. Responses indicated that a majority of users (52%) learned more and 12% learned a lot more compared to “traditional” learning, while 31% of them learned the same as in traditional learning schemes. This is a clear positive outcome of the package. This Internet-based package is attractive while presenting basic engineering notions, gives real-world examples and allows practical experience on real things, even remotely located such is the case of remote labs.

As regards the rate of learning, 50% learned faster and 10% learned a lot faster, while only 7% learned slower than in traditional learning. A possible reason for learning faster may be the variety of resources offered. The simulators covered different aspects of the theory but also a certain degree of overlapping was kept, that is similar knowledge was needed to run some simulators.

Most of the users (78 %) reported that the use of simulators increased the learning outcomes, while 77% thought that the objectives of the package were made clearer by the use of simulators.

Additionally, 80 % of the users said that the learning package was completed without any external help. While this is a high score, it has to be improved by a more detailed theoretical description with more references to open sources of information. The simulators have to be carefully documented, but the student must be encouraged to give his own explanations for some simulated behaviours.

In summary, results on users reported learning suggest that the package was successful in meeting its specific instructional goals of teaching the basics of motion control in an attractive way

4. CONCLUSIONS AND FURTHER DEVELOPMENTS

New ways to supplement the traditional learning schemes are needed in control engineering education. This paper reports a successful attempt to use the latest technological and instructional developments in teaching motion control. The integrated use of traditional theory, dynamic and interactive simulators, games, remote labs is giving a coherent and enriching learning experience that opens new perspectives to the learner.

Further versions will build on the basis of this successful package and will attempt to propose more attractive simulators and to enrich the learning experience by more appropriate games. AC/induction motors as actuators which are massively used in industry will be modeled and relevant simulators will be implemented in Easy Java. Other non-linear models will be considered, as all the already simulated models are linear. The differences between real-world and laboratory simulations will be more clearly indicated with respect to all facets of motion control.

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