AN EXAMPLE OF PRACTICAL LABORATORY TRAINING IN CONTROL THEORY COURSES FOR DIPLOMA STUDENTS IN MECHATRONICS

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Abstract - **Subject of the paper is the practical training complementing the theoretical course about control engineering and automatic feedback control in Bochum in 2006.**

The university of applied sciences of Bochum started with diploma courses of mechatronical engineering in 1993/94. Especially the reading of control theory and the practical education then had to be renewed in comparison to the courses in mechanical engineering. Improvements of applications of sensors and actuator systems were essential, as well as changes of software applications in the field of control techniques .

The paper describes the new equipment and facilities of the laboratory of control and feedback control systems (SRT-LAB) developed in 2006. This was done after several steps of improvement.

In practical trainings the students receive the opportunity to consolidate the learning matter on exemplary mechanical systems like a ball on a seesaw, a turntable, a crane system and a two tank system.

The philosophy of the configuration is equal for each system: A process computer (MS-Windows PC) performs the task of the controller. The software WINFACT-BORIS provides graphical structure programming by the students. The software is easy to learn and also flexible in hardware adaptation. The multi purpose data acquisition card PCI-6229mx by National Instruments provides a wide range of digital/analog signal processing and sensor interfaces. Several typical sensors for control applications to measure mechanical and electrical values are used. The actuators are represented by DC- and EC-motors, solenoids and pumps together with sufficient controller modules. A prescribed series of tests being synchronized to the lessons provides exercise in system identification and controller design.

Each test rig is arranged in pairs – the mechanical system and also the IT-system – in order to optimize the teacher / student relation as well as the student / test system relation.

Index terms **– laboratory training, control techniques, mechatronics, virtual test rig**

I. INTRODUCTION

The university of applied sciences of Bochum started with the courses in mechatronical engineering in winter 1993. In those days the laboratory for control techniques was mainly characterized by mechanical experimental equipment. Laboratory exercises with control processes like the temperature control of a small oil tank system or the level control of a huge two tank mono-pump system where available to the students of the mechanical engineering courses. The step response time of both systems was around one hour. A small amount of technical sensors and actuator systems used in industrial applications where part of the experiments. Nether student were introduced to apply data acquisition cards to process-controllers; nor was the corresponding software available to handle tasks like sensor measurement, signal filtering and real time process control. A few special industrial controller modules could be tuned to the process, but the exercises mainly concentrated on system identification by step responses recorded by an x-y-plotter. For more theoretical system analysis a specialized analog computing device to demonstrate PTn and ITn systems with oscilloscope display was used.

The student test rig relation was operated with six or more students practicing on one experiment quite unacceptably.

The new orientation of the two faculties M and E (for mechanical engineering and electrical engineering), cooperating and starting the course mechatronical engineering, demanded the necessity to initiate the renewal of the practical education. Endeavors had to be done designing applications with sensor and actuator systems, as well as software applications in the field of control techniques. MS Windows PCs were chosen as platforms for hardware equipment and software tools. DAQ-cards for measurement and process control where chosen as well as software tools like a block oriented simulation language to design measurement and control structures. Smaller experiments where designed as one test rig should fit on the bench together with PC and monitor. Eventually the number of test rigs was increased over the years so that now one test rig is available for two students, the optimal relation, and half a bench in size.

The following article describes the concept and equipment of the laboratory.

II. PURPOSE AND CONCEPT OF THE LABORATORY

The lesson in feedback control theory discusses topics like

- introduction to feedback control
- system analysis by mathematical and physical modeling
- system analysis by identification methods like step responses
- transfer function method
- theory and use of the proportional, integral and derivative (PID) controller
- controller design among other theories: applying the transfer function method by compensating the plant dynamics
- stability theory by Nyquist and Hurwitz

The laboratory exercises are held in order to complete the learning process by understanding

- the basic system behaviours described by 1st and 2nd order linear differential equations (especially by examples with PT1-, PT2-, I- and IT1-characteristics)
- the identification method by test functions (especially by the step response method)
- the basics of control loops with feedback
- controller design with compensating method

Apart from this theory based items the learning process is focussed on practical and technical problems like

- design of analog signal flow structures in a MS Windows workspace
- real time signal processing
- measurement accuracy, signal conditioning and sensor interfacing
- special electronic devices driving actuators and conditioning sensor signals
- special software tools for control applications, e.g. block oriented simulation, frequency response plotter.

The concept of each exercise will follow the same pattern according to Fig. 1. The mechanical example system is providing the task to build up a control loop. The four system types being realized are a ball on a seesaw, a crane system, a turn table and a two tank system.
Depending on the applied sensors and actuators a specialized peripheral electronic does the signal conditioning. This described unit represents the control plant.

Just similar in each system is the part of the process controller. The 2GHz-Pentium PC with MS-XP contains the DAQ-card NI PCI-6229 [NI2006] with four DA channels and 32 AD channels and several programmable digital signal I/O [NI].
The new National Instruments m-Series DAQ card is very convenient for this purpose providing huge functionality as well as low cost pricing.

The programming of signal structures for control and measurement purposes is done with Winfact7 [Kahlert] by Dr. Kahlert Engineering. It is a program package containing block oriented simulation (BORIS) Fig. 2, signal graph documentation (INGO), linear system analysis (LISA) and further software modules for control engineers in industry and education. There are installations all over German universities, in Europe and Asia. Consolidating literature is available [Kah2005].
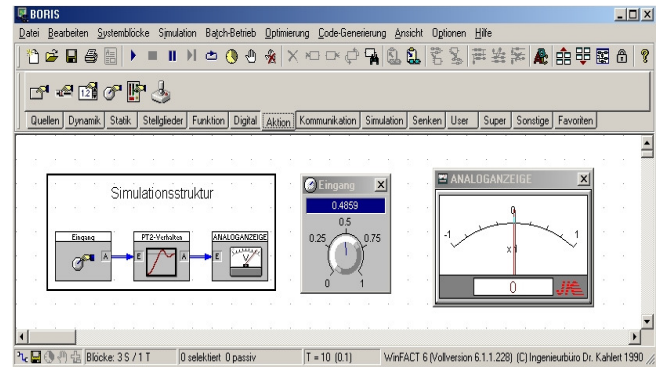

Fig. 2: WINFACT7-BORIS Workspace

In order to interface the signals of the DAQ card with the simulation software structure a special driver had to be designed. The first version just used the provided NI-DAQ library. This turned out to be not very efficient. Reasons are the library design for purposes with one way data acquisition only. Sampling rates never increased 200Hz. An individually programmed driver using basic NI-DAQ functions done by Dr. Kahlert Engineering finally obtained sampling rates up to 2 kHz with two bidirectional analogue signals. This was then more than convenient for mechanical system control.

III. STUDENTS WORKSPACE

In the laboratory the test bench contains two workspaces for two couples of students. Each test rig consists of the example plant, the PC providing the software and the power supply and is designed identically. Fig. 3 shows the bench with the two seesaw systems as an example. In order to gain additional workspace the TFT monitors are mounted to the wall.
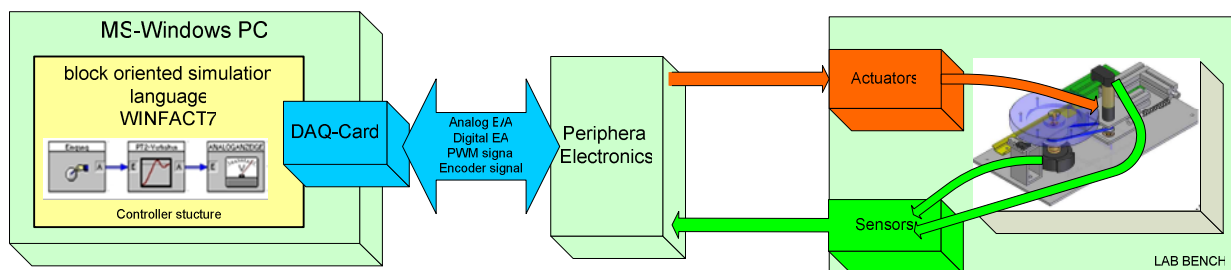

Fig. 1: Signal Structure of test rig with turn table system as example

students. There are always two identical units on the desk. Fig. 5 to Fig. 8 shows each system in virtual 3D drawing in Solidedge14.
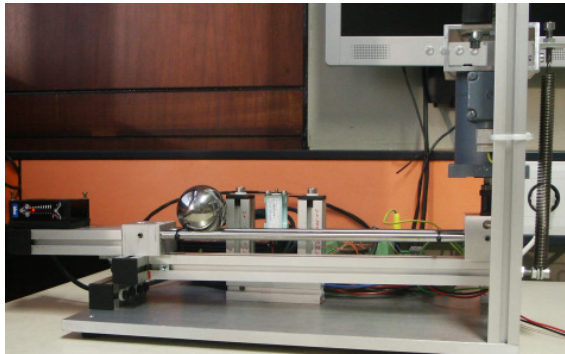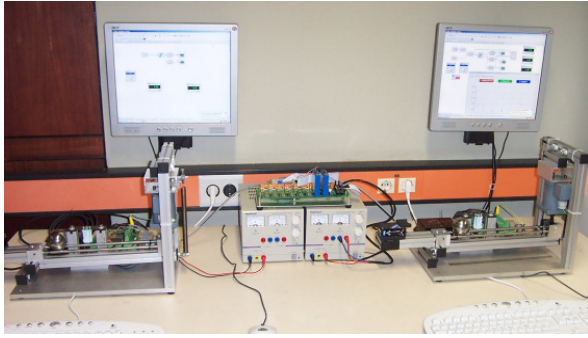

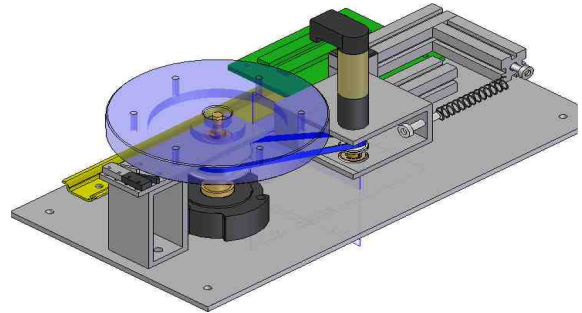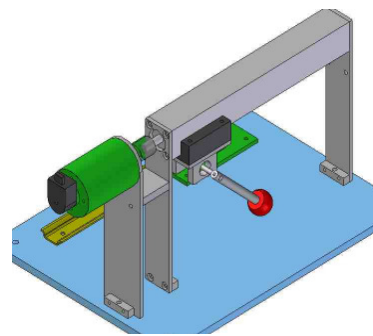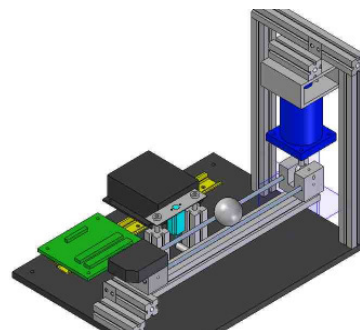Fig. 5: Turn table system

Fig. 3: Bench with two seesaw systems as an example.

A comparison with the former seesaw system [Heß1997, Wey1999] shows the progress/difference: The former system Fig. 4 had about double the size than the actual ones have. Up to five students had to manage one of those test rigs. Nowadays each student is closer to the exercise, whether in handling the mechanical system or in designing the software structure.

Fig. 6: Crane system

Fig. 7: See saw system

Fig. 4: Former seesaw test rig.

IV. THE MECHANICAL DESIGN OF THE FOUR TRAINING SYSTEMS

All mechanical systems have been totally designed by using the 3D-CAD Tool Solidedge14 by Unigraphics [UGS]. They are based on an aluminium panel of 300x150mm size. The panel also contains the DAQ terminal PCB and other peripheral electronics in the back. With very few parts, only one actuator and two sensors, it's functionality can be easily understood and handled by
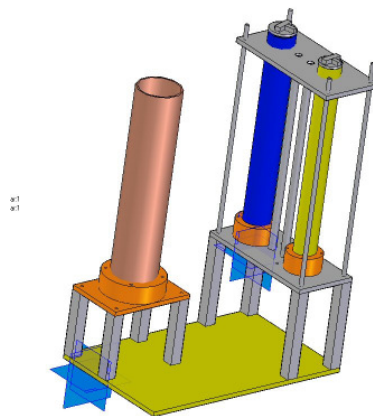

Fig. 8: Two tank system

The mechanical part of the above described units has been build in the faculty workshop during one semester. All drafts are available for further multiplication.

V. ACTUATORS AND SENSORS

A variety of typical actuators used in mechatronical systems is provided. Because of the size of the individual unit the actuator principle is electromechanical. However, the parallel laboratory used for practical exercises in the mechanical engineering course has recently been modernized with the same idea and additionally using pneumatic actuators.

Several sensor principles are required to obtain the control value signals as there are current, pressure, angle, displacement, distance and rotating speed.

Table 1 gives detailed information about the individual allocation of actuators, sensors and driver circuits.

System	Actuator	1st Sensor	2nd Sensor	Actuator driver
See saw	Solenoid	Current sensor	Displacement sensor	Analog H-bridge controller
Turn table	DC-motor	Motor axis encoder	Angle encoder	PWM circuit
Crane	EC-Motor	Motor axis encoder	Angle encoder	EC-motor driver
Two tank	DC-pump	Pressure sensor	Pressure sensor	OP-AMP circuit

Tabl. 1: Allocation of actuators and sensors

VI. SYSTEM IDENTIFICATION

As already mentioned before the software WINFACT7 is used for time critical measurement purposes as well as for process control structures. The signal structure used to obtain a step response from the turn table system is shown in Fig. 9 (top down: test signal generation, DAQ interface, signal conditioning and time plot). Frequency response measurement is possible as well.
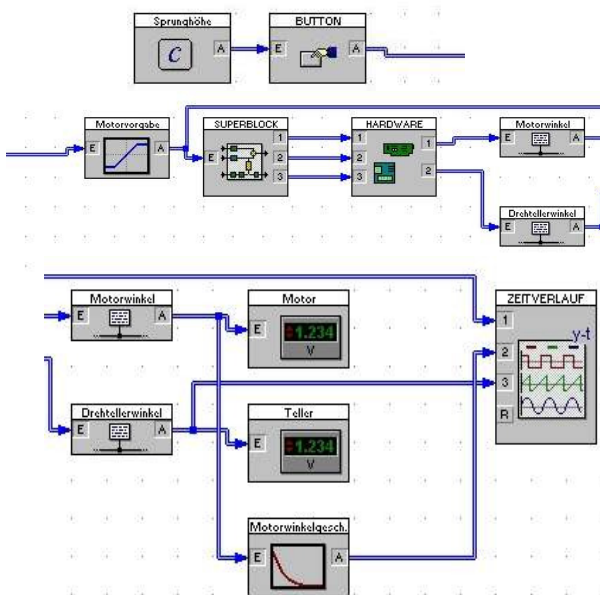

Fig. 9: Step response structure

The students have to design the measurement structure in the first step followed by taking the step response of the process. As a result the curve is plotted and evaluated as shown in Fig. 10 using the time plot functionality.
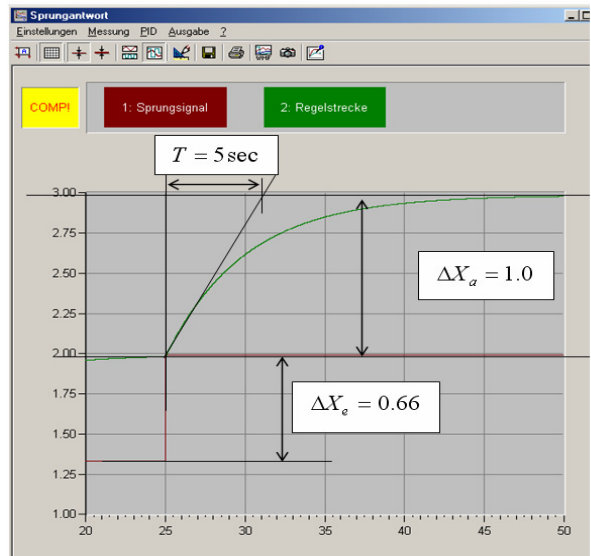

Fig. 10: Evaluation of a PT1 step response.

VII. DESIGN OF CONTROL LOOP

In the following laboratory session the control loop is designed using the same software tools as before. The plant transfer function has been obtained from the 1st session. The theoretic control algorithm can be calculated for instance by the method of delay compensation .

Practical problems have to be solved dealing with actuator value saturation, algebraic loop restrictions and estimating the correct set value range. As it was important in the 1st session the real time process has to be dealt with. Finally in all cases a cascaded control loop is the result (Fig. 11) .

As an example the time plot of the turn table angle which is controlled by two cascaded controllers is shown in Fig. 12. The long response time results from the deliberate use of a very soft rubber belt between motor and turn table.
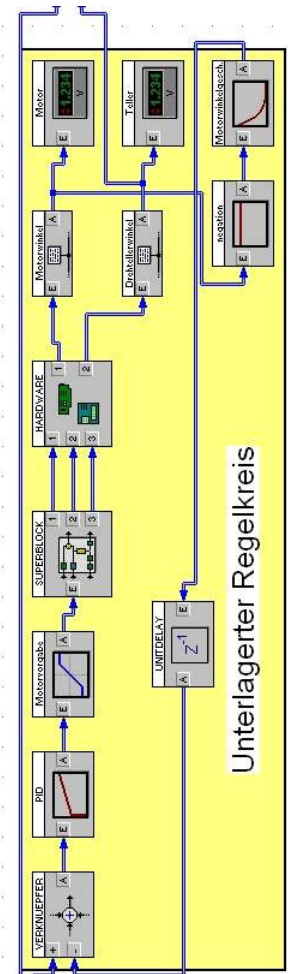

Fig. 11: Control loop structure of turn table system (inner loop with speed control of turn table)
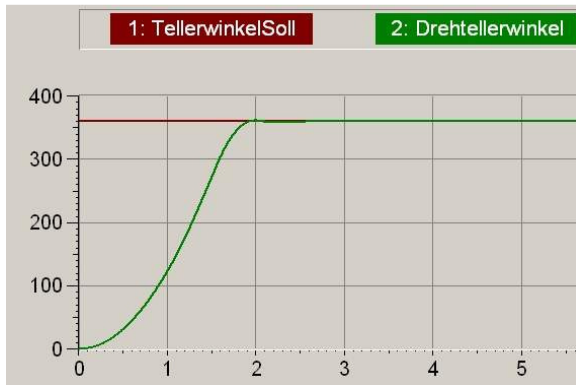
Fig. 12: Time plot of set value and process value, turn table system.

VIII. VIRTUAL TEST RIGS

Additionally to the practical laboratory a supplementary virtual lab will fully engage the students in the learning process and will prepare for the practical lab course. It is designed using the WINFACT7 Flexible Animation Builder tool and provides an interactive, dynamic lab environment on the home PC. Supplied on the laboratory CD it comes together with a free Winfact7 Student Edition. Detailed nonlinear simulation models of the four experimental systems are combined with pixel animation of the primary dynamic components. The user can manipulate sliders and buttons while the simulated model reacts and is animated like the real system.

The students are motivated to exercise with the software at home exploring the four animated test rigs. It is possible to undertake the same experiments for system identification and control loop design as scheduled in the two laboratory sessions.
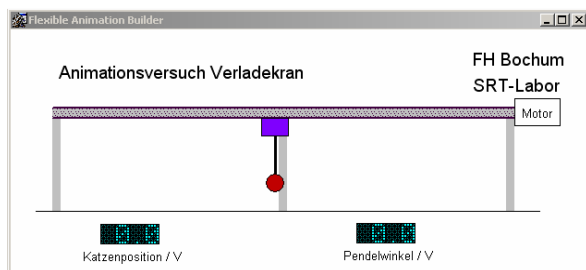

Fig.13: Animated model of crane test rig.

IX. CONCLUSION

Practical learning of control techniques in mechatronical engineering courses demands specialised laboratory equipment integrating several engineering domains. The described concept of experimental test rig is flexible to handle and to maintain in the future. Due to the universal block oriented simulation software WINFACT signal structuring for measuring and controlling purposes can be trained practically. The hardware part provided by four interesting mechanical systems enables students to feel dynamics and understand the nature of differential equations. By the way they get used to customary sensor and actor systems.

Simplification and reduced size leads to the possibility to provide direct student access to each test rig in times of increasing student numbers. Building it in pairs of identical experiments also reduces the effort of supervising the student couples.

This kind of practical learning with tight schedules and exactly documented tasks corresponds to the problem of the short time window that laboratory learning has got in the usual time table. Experiences with modern project labs [Ker2006] show that groups of students working out a control task for a given system during the semester often have time problems at the end when preparing for the exams. On the other hand the transfer of theoretic knowledge into practical skills is mostly not efficient in project labs.

In the authors opinion the described equipment is a good compromise between the necessary amount of knowledge transformation and the given time for practical exercises in the laboratory.

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