DIGITAL COMPUTER CONTROL EXPERIMENTS IN THE CONTROL GROUP OF ETH-ZUERICH

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Abstract. Experiments that have been realized in a digital computer control laboratory are described in this paper.

A set of 17 experiments that are used in undergraduate and graduate laboratory assignments as well as in research are briefly described.

Three experiments, namely a coin exchanging machine, an inverted pendulum and the tension and speed control system in a tape transporting mechanism are then presented in some detail.

The experience that has been obtained from running the laboratory for many years is summarized.

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Overview of experiments
Detailed description of some experiments
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Conclusions
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Keywords. Education, Teaching, Control engineering computer applications, Computer control laboratory, Computer control experiments.

INTRODUCTION

Work in the laboratory and application of theoretically obtained results to practical problems are of great importance in the curriculum in electrical engineering at ETH-Zürich. This is especially true for the education in control engineering where the gap between theory and practice is perhaps greater than in other fields; due to the fact, that accurate models of processes are often difficult to obtain, and also due to the fact that many processes of practical interest are nonlinear or timevarying.

Based on these facts, strong emphasis is put on practical work during the education at all stages. In control practical work starts in the 5th of the 8 semesters of the undergraduate program with many experiments in the fields of analog computation, electromechanical control systems, digital systems, computer controlled systems, computer aided design.

Students carry out three projects during their undergraduate studies (about 300 hours per project). Many of these projects are done in the laboratory.

Experiments have also been especially designed to complement the theoretically oriented courses in the one year graduate program in control engineering offered by the department.

The application of theoretically obtained results to laboratory scale processes and experiments is also important in many graduate and research projects, including Ph.D. theses.

In this paper we will only treat experiments done with digital computers to provide ideas, how a practical education in the field of automation by micro- and minicomputers can be done.

The outline of the paper is as follows: Section 2 will provide an overview on the installations and experiments. Three examples are provided in some detail in section 3. Experiences are summarized in section 4 and conclusions stated in section 5.

OVERVIEW OF EXPERIMENTS

This section will provide an overview on the installations and on the experiments.
Processes

One of the most difficult things in designing useful laboratory experiments is the choice of the processes to be automated. For didactic reasons, the processes should be simple and easy to understand in a short amount of time. To be of practical importance, processes should be rather large, reflecting industrial applications. According to the tradition of the control group and to the knowledge of our students, the processes are mainly taken from the field of electromechanical systems.

Typical processes used in our lab, roughly grouped in three categories, are represented in Fig.1 to 3.

Computer installations for process control

The following digital computers equipped with a process control interface are available to carry out the experiments:

- HP 2100
- PDP 11/60
- PDP 11/45
- PDP 11/03

Some of the processes are always connected to the same computer, others are used with different computers.

The following language-levels are used to program the computers:
- assembly level with macro library
- Pascal
- Basic
- Fortran
- Lasic (Logical Basic)
- Modula (a real time language)
- Portal (a real time language)

Due to the fact that testing and debugging take very much of the development time, programs are usually developed on the installation on which they are used. Relatively little use is made of Cross-Software.

Overview of experiments

We provide a brief overview on many experiments in this section. Goals to be reached are described for different courses and related experiments are summarized.

A) Undergraduate control lab (5th, 6th term)

This lab consists of simple one afternoon experiments to introduce sequencing control and classical control methods. A course introducing classical and state variable techniques is given in the 4th, 5th and 6th term.

Examples

Traffic lights (Huguenin and co-workers, 1980).

A model of traffic crossing with 5 lanes in the city of Zürich is controlled by a computer. In automated operation, the system has six different states. The student writes a BASIC program (Logical Basic) for fully automated operation of the crossing. He does experiments on the installation.

Highway warehouse (Mäder and co-workers, 1975)

Wood blocks can be stored and retrieved from a fully automated model warehouse with 360 storage places. Experiments with the crane position control subsystem (pre-programmed in Fortran) are carried out by the student. A pulse width controller is used.

Coin exchanging machine (Huguenin and co-workers, 1980)

A fully automated coin exchanging machine using small balls as coins is available. The students write Pascal programs for simple changing strategies and operate the installation.

Speed control of a DC-motor

A 4 kW DC-motor is controlled with thyristors. The student has to investigate discrete proportional-integral-differential controllers programmed by the assistants. The student can change the controller parameters and the sampling time and investigate the system theoretically and practically.

Three basin level control system (Huguenin and co-workers, 1980)

On-off and proportional-integral controllers are used to control two levels in this system. The student does verify the operation of all parts and the theoretically obtained model. He then operates the system with a preprogrammed solution.

B) Undergraduate student projects

Typical goals at this stage are design and implementation of state-variable feedback and output feedback controllers on different processes. The student has much more time available for a project than for a laboratory assignment, so that he can carry out the entire design cycle.

Three mass-spring system

Output feedback controllers have been designed and implemented on this system of 6th order.

DC-servo

State variable feedback control has been successfully implemented on a 4th order servo by using an observer (Huguenin, 1979). Two systems are controlled simultaneously by use of a real time operating system.
Fig. 1: Processes used in the undergraduate laboratory

tape transporting system (tension and speed control)

antenna positioning (extremalizing control)

Fig. 2: Processes used for undergraduate projects

three mass spring system (adaptive control)

tape transporting system (tension and speed control)

DC motor (speed control)

DC servo system (state variable feedback, observer)

inverted pendulum (stabilizing control)

model train (parallel programming)

heating system (estimation and control)

Fig. 3: Processes used in graduate and research work

three mass spring system (output feedback)

traffic crossing (sequencing control)

elevator (sequencing control)

coin changing machine (sequencing control)

highbay warehouse (sequencing and position control) 360 positions
Inverted pendulum (Huguenin and co-workers, 1980)(Maletinsky and co-workers, 1981)

An inverted pendulum is controlled by different control algorithms. Swing up strategies have been developed for the single stick pendulum and stable controllers have been realized for all equilibrium states for a two stick pendulum.

C) Graduate control laboratory

Some experiments have been especially designed to complement the theoretically oriented lectures in the graduate control courses, i.e. identification, adaptive control, control by microprocessors. Experiments in adaptive control are summarized in Schaufelberger (1977).

Adaptive control of DC-generators (Glattfelder, Huguenin, Schaufelberger, 1990a)

Several adaptive control methods (model reference, selftuning) are used to control small DC-generators with varying turbine speed.

On-line identification (Maletinsky, 1975)

Several programs are available for on-line identification of different electromechanical systems.

Speed and tension control of the tape transporting machine (Huguenin and co-workers, 1980)

Design and implementation of a controller consisting of two proportional-integral controllers and a static decoupling network is another example of a laboratory assignment at this stage.

D) Graduate student projects

Implementation of advanced control strategies on nontrivial examples are goals at this stage.

Speed and tension control in a tape transporting machine

State variable feedback control with observer has been implemented on this two input, two output system.

Positioning of antenna

Adjustment of antennas for optimum data transmission as an example of extremalizing control has been designed and implemented.

Parallel programming

Implementation and use of two recently developed languages (Modula 2: Wirth (1980), Portal: Lienhard (1978)) to control different processes is also a typical assignment at this stage.

E) Research projects

Results as obtained in the theoretical investigations in research work are often implemented to obtain insight into the feasibility of the results obtained.

Adaptive control (Maletinsky, Schaufelberger, 1974, Maletinsky, 1975, Schaufelberger, 1977)

When the masses in the three mass-spring system change, identification and adaptation techniques can be tested easily.

Power systems model

A computer controlled power systems model with three generators is under construction together with other groups in the department. It operates at 4 kW level and will be used for experimental work on new control algorithms in power systems.

Design principles for microprocessor based control systems (Glattfelder, Huguenin, Schaufelberger, 1980b, Huguenin, 1980)

Use of distributed processing for decentralized control applications and real-time simulation is studied in this work.

DETAILED DESCRIPTION OF SOME EXPERIMENTS

Coin exchanging machine (Huguenin and co-workers, 1990)

The machine is represented in Fig.6. Small balls are used as coins.

This is a typical example for sequencing control. If a ball enters the system, its diameter and weight are determined. It is then sorted into the appropriate category. Exchange "money" is given to the user according to the program and exchange tables used. Subroutines are prepared for different subproblems, so that the student is able to write a Pascal program for the main sequence in one afternoon.

The installation is also used for demonstrations.

Fig.5 shows a display on the screen of the internal state of the machine from a demonstration program written by an assistant.


The system is represented in Fig.6. The length of the track is 4 m. Several different swing up and stabilizing control techniques have been realized for the single stick pendulum with the measurable quantities x and \( \dot{\varphi} \) and with the control signal u (armature current of driving motor). Results from an
Fig. 4: Ball exchanging machine

Fig. 5: Part of screen display

Fig. 6: Inverted pendulum

Fig. 7: Results of pendulum experiment

Fig. 8: Tape transporting machine

Fig. 9: Results of control of the tape winding machine

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experiment are represented in Fig.7. Three different controllers are used in sequence in this case, namely

phase 1: swing up
  open loop control by a signal which is computed off-line (bang-bang)

phase 2: nonlinear feedback control
  a heuristically designed nonlinear feedback control scheme is used to bring the pendulum to the vicinity of $\gamma = 0$.

phase 3: stabilizing control
  a linear pulse-width controller is used to stabilize the system in the upper equilibrium position.

A second stick has recently been added at the end of the first one. All four equilibrium positions of the new system can be satisfactorily controlled. No new measurements are used, but the second stick is observed.

Tension and speed control of a tape transporting machine (Kaiser, 1978, Huguenin and co-workers, 1980)

The idea for this experiment originated from problems in the area of paper and textile machine control. The hardware is represented in Fig. 8.

The system has two inputs $u_1$ and $u_2$ and three outputs $u_{T1}$, $u_{T2}$ and $\gamma_2$. Two inputs and two outputs are used in normal operation.

In a graduate project Kaiser (1978) developed a model for the system. He then used a state variable feedback controller with observer. The results depicted in Fig.9 are taken from his work.

In his doctoral dissertation Fessas (1979) proved that completely decentralized control of the system is possible by decomposing the system in $u_1 \rightarrow u_{T1}$ and a $u_2 \rightarrow \gamma_2$ system.

Results from using the system in the classroom with two classical proportional-integral controllers and a static decoupling network can be found in the internal report by Huguenin and co-workers (1990).

EXPERIENCE

The experience gained from operating the process control laboratory for many years may be summarized as follows:

Lectures in the classroom can be made attractive by having a set of well-prepared demonstration examples at hand. The students can see that theories that have been developed in the classroom can be put to work on small problems.

During the laboratory assignments the student gets a feeling for a wide range of possible applications of micro- and minicomputers to the processes he knows best, namely electromechanical ones.

By doing a project on a laboratory installation he gets a deeper insight into one specific problem. He can see the entire design circle, starting with basic ideas and design programs and ending by testing the entire solution in the laboratory.

During a research project it is also useful to implement the results on practical problems. New ideas that have been overlooked in the purely theoretical work will often result from this.

For the student the experience can be summarized as positive. The main drawback is probably that as in all laboratory work much time is often wasted on unimportant details.

For the teachers, a considerable time and effort is required to install and operate a laboratory of the size and equipment described above. One must be very careful, not to lose the important aspects of teaching control out of sight, because one has to look at many different aspects: choice, construction, installation and maintenance of process and computer hardware; software development etc.

CONCLUSIONS

A process control laboratory that has been operated for many years has been presented in this paper.

The authors hope that some of the ideas that have been presented will be taken up at other institutions and that an exchange of information on experiences gained in this kind of laboratory work will result from this work.

ACKNOWLEDGMENT

The main work in realizing the experiments in the control laboratory of the control group at ETH has been done by many co-workers, assistants and students. Without their continuing efforts the laboratory could not be operated. Their work is acknowledged.

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