# Experiments in Control Education

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**Abstract:**
This papers analyses stresses for change in the control engineering education and proposes some solutions based on a broader use of experiments and guided individual or teamwork of students in laboratories. It is starting with analysis of the institutional context of education in the control area and continuing with some examples of the author's experience in building up control experiments.

**Keywords:** Control education, Learning by doing, Student-centred approach, Resource based learning, Teleexperiments, Vocational standards

## 1 Introduction

Today, due to the information revolution accompanied by many other changes in the educational environment, universities are worldwide facing dramatic changes in the educational schemes, forms and methods.

In the previous development, the basic aim of education – acquisition of knowledge, skills and attitudes – has in many cases been violated by preferring orientation on gathering knowledge rather then skills and attitudes (which are not easy to measure). The education became too academic. So, as the 1st motivation for a change, one could mention the increasing gap between the too formal academic education and the real needs of industry. The necessity of deepening the vocational aspects of engineering education has been internationally recognized and reflected (see e.g. the running EU programmes, like Leonardo and Socrates, or the 5th framework projects). This new trends, together with the demands on promotion of the student mobility and of the quality control in education, lead to requirements on setting up vocational standards for particular areas of education.

**International Journal of Computing Anticipatory Systems, Volume 9, 2001**
**Edited by D. M. Dubois, CHAOS, Liège, Belgium, ISSN 1373-5411 ISBN 2-9600262-2-5**

## 2 Vocational Standards

One possible solution to eliminate the increasing gap between the higher education and the practice is known as the competence based learning. Since the 1980s it grew out of dissatisfaction with existing qualifications, when many employers claimed that graduates knew much but could not do anything. While the academic qualifications are mostly based on pure knowledge, competencies formulated in cooperation with industrial and commercial bodies represent combination of skills, knowledge and understanding, or, in other words, practical application of knowledge and understanding (Glanville, 1995). Strengthening of the links between universities, industry & commerce requires joint development of competence-based higher education also in the control area. Since this should balance the mostly conservative requirements of practice with the latest (and often not sufficiently proven) research results, the development process cannot be expected to be straightforward. Different profiles of higher education institutions may also lead to a broader formulation of standards on the could-should-must bases. It is obvious that the competence based approach oriented to developing skills and attitudes will require significant part of the education to be carried out in laboratories, or in the work on conditions.

## 3 New Degree Structure and Study Programmes

In Slovakia and also in many other European countries, the above demands are combined with the necessity of adoption of the 3 level degree structure (bachelor/master/PhD) instead of the traditional elite engineering education leading to Dipl.Ing. degree. The new scheme should allow raising the student figures at the 1$^{st}$ (undergraduate) level. Since the financial inputs to higher education are not following the increased output figures, it is expected to achieve these figures by increased economy of scale, i.e. by forming not too many but more comprehensive study programmes. In looking for international standards in this area, one can find that they are relatively well developed for the area of computer science. However, in the Anglo-American environment, some other headers mostly cover the control area. So, by leaving the older Dipl. Ing. degree strongly influenced by the German environment with clearly defined position of “Automatisierungs- Regelungs- und Stuerungstechnik”, it is also necessary newly to define the position of the control education. Since the control is considered as an interface between the computer & information systems on the one side and the controlled processes on the other side, it is quite normal that this can be approached from both sides. Since the range of different processes is much broader than that of computers, it inherently brings much higher diversity also into the education. It is the task of the control community and of its bodies like e.g. IFAC to contribute to the education transformation, to overcome isolationism of particular disciplines and to start to think about approaching the young generation already during the comprehensive secondary education.

## 4 Computers in Control Education

As an internal motivation for a change in the educational forms and methods in Control Engineering one can also consider new tools brought by the development of Information Technologies, as e.g. the mathematical software packages Matlab/Simulink, or different Computer algebra products - Maple V, Mathematica, Derive, etc. The other pole of these new possibilities is given by the development of multimedia and Internet. Active involvement of all these tools enables development of highly interactive course materials supporting student-centred approach and reasonably changes the course activity design.

## 5 Learning Events

Besides of the traditional lectures and classes, the new environment requires in a high extent (Clarke, 1995). Laboratory work, Seminars, Exams, Diploma Thesis, Term and Diploma Projects, all based not just on individual student's work, but also on team activities. Using of ICT for Control education is dominating, but, at the same time, the Control education is used for promoting skills in using ICTs. The new aspects are influencing:

- Curriculum Design,
- Content and Organization
- Teaching,
- Learning and Assessment
- Student Progression and Achievement
- Student Support and Guidance
- Learning Resources
- Quality Management and Enhancement.

## 6 Plant Scaled Models for Education

Up to now, the experiments in control education are being introduced mostly due to the personal initiative of particular teachers. By some elements of play and by a clear feedback, they are positively influencing student's motivation to learn. As it was already mentioned above, the work with different plant models can be crucial in developing skills and attitudes required by industry.

Below, several examples of plant models used in education at the author's workplace are shown (Žáková et al., 2000). The motivation to choose exactly these plants has been given by:

- clear physical “visibility” of the controlled dynamics (mostly Electro-mechanical systems),
- time constants in the range ms-minutes,
- safety manipulation,
- reasonable price of purchase or of the own development,
- availability of sensors and actuators,
- easy maintenance.

In the last years, these criteria have been extended by the requirement of

- possible approach via Internet.

This should open the access to the experiments (Huba and Žáková, 2000) and at the same time also develop skill in the use of Internet, which is becoming to be important communication and control tool.

According to the orientation of the author’s working group (Nonlinear control) we have preferably chosen

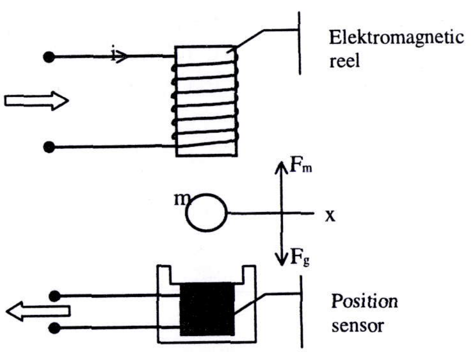
- plants with **nonlinear and possibly “difficult” dynamics**.

Besides these, also simpler experiments are used to build up skills at the initial level of control education.

### 6.1 Magnetic Levitation

Broadly used equipment of different professional producers or of the own development. We use product delivered by the Czech enterprise Humusoft, together with the I/O converters card compatible with the Matlab/Simulink environment. The duration of transient responses is in the range of ms. For an optimal control it requires sampling periods in range of 0.1 ms. It is appropriate for an online access via Internet.

6.1.2 Principal Scheme




x – vertical position of the ball
$m_k$ – mass of the ball
g – gravity constant
i – current of the reel

$$\ddot{x} = \frac{i^2 K_c}{m_k (x - x_0)^2} - g$$

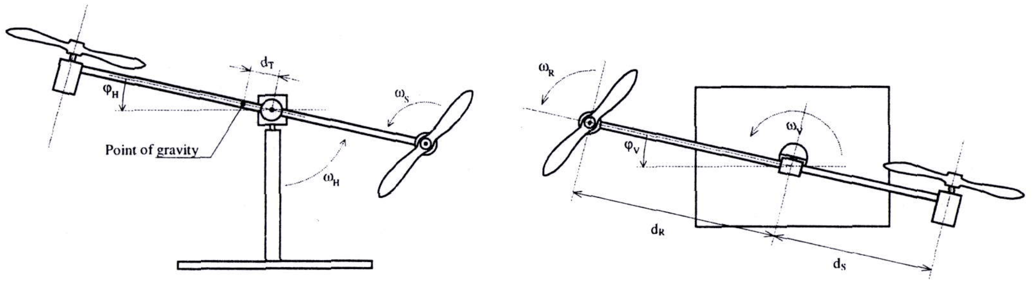
6.1.2 Measured and Controlled Signals

- ball position (inductive sensor),
- voltage controlled current source.

6.1.3 Task Solved

**Manual control** (actually, not practicable – motivation for the automatic control);
**Identification of an unstable nonlinear system** (steady state plant characteristic – curve fitting, step response analysis requiring closed loop stabilization of the starting position and elimination of the measurement noise by multiple measuring);
**Linear control** (PD and PID control based e.g. on the generalized method by Ziegler and Nichols);
**Nonlinear control** (based e.g. on the generalised method by Ziegler and Nichlols, exact linearization method, control of constrained systems);
**Fuzzy control, Neural control**.

### 6.2 Helicopter Rack Model




The equipment is result of the own development. A different professional version, but without possibility to measure the propeller speed of rotation is sold by Humusoft.
The duration of transient responses is in the range of s. For the online access via Internet it would need some construction modification (safety in the limit positions – wireless communication and power supply via collectors). Also the plant identification requires some steps, which are still not possible via Internet.

6.2.1 Mathematical Model

$$\frac{d\omega_R}{dt} = \frac{1}{J_R}\left(c_{uR} i_R - k_{MR}\, sign(\omega_R)\,\omega_R^2 - c_{\mu R}\omega_R\right)$$

$$\frac{d\varphi_H}{dt} = \omega_H$$

$$\frac{d\omega_H}{dt} = \frac{1}{J_H}(-k_{FR}\, sign(\omega_R)\,\omega_R^2 d_R + \frac{1}{2} c_{uS} i_S - c_{\mu H}\omega_H + m_G \cos\varphi_H (g d_T - d_S^2 \omega_V^2 \sin\varphi_H))$$

$$\frac{d\omega_S}{dt} = \frac{1}{J_S}\left(c_{uS} i_S - k_{MS}\, sign(\omega_S)\,\omega_S^2 - c_{\mu S}\,\omega_S\right)$$

$$\frac{d\varphi_V}{dt} = \omega_V \ ;$$

$$\frac{d\omega_V}{dt} = \frac{1}{J_V + m_G d_S^2 \cos^2 \varphi_H}\left(k_{FS}\, sign(\omega_S)\,\omega_S^2 d_S \cos\varphi_H - \frac{1}{2} c_{uR} i_R \cos\varphi_H + \right.$$

$$\left. + 2 m_G d_S^2 \omega_V \omega_H \sin\varphi_H \cos\varphi_H - c_{\mu V}\,\omega_V\right)$$

$$y = (\varphi_H, \varphi_V)^T$$

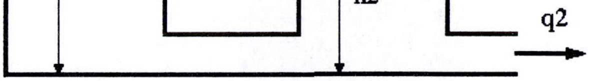
6.2.2 Measured and Controlled Signals

- 2 axis angles, 2 motor currents, 2 angular velocities of the propeller drives,
- 2 motor voltages.

6.2.3 Task Solved

**Manual control** (actually, not practicable – motivation for the automatic control)
**Identification of an unstable nonlinear system** (analytical identification combined with experimental identification - identification of particular nonlinear terms by planning experiments– curve fitting, step response analysis requiring closed loop stabilization of the starting position, measurement & quantization noise analysis);
**Linear control** (LQ control based on linearization around fixed operating point)
**Nonlinear control** (modified exact linearization to deal with unstable plant zeros)
**Fuzzy control, Neural control**.

**6.3 Hydraulic Plant – One, or Two Tank System**




$$S_1 \frac{dh_1}{dt} = q_1 - \alpha_1 \sqrt{h_1 - h_2}$$

$$S_2 \frac{dh_2}{dt} = \alpha_1 \sqrt{h_1 - h_2} - \alpha_2 \sqrt{h_2}$$

This plant also represents a very popular product produced in many modifications by several enterprises. The duration of transient responses is in the range of minutes.

Appropriate for the access via Internet, but in order to enable the on-line identification and reconfiguration (one or two tank system, or a combination of two plants for 2x2 MIMO system as the 3-, or the 4-tank system) it needs to be equipped by remotely controlled valves.

6.3.1 Measured and Controlled Signals

- liquid levels $h_1$, $h_2$ (ultrasonic sensors),
- voltage controlled power amplifier for the pump control.

6.3.2 Task Solved

**Manual control** (relatively easily practicable, but tedious – motivation for the automatic control)

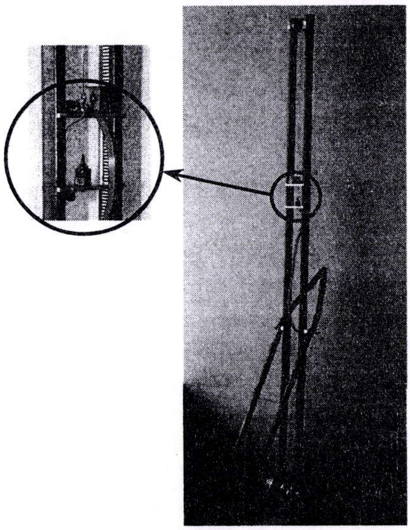
**Identification of a stable nonlinear system** (analytical identification combined with experimental identification of particular nonlinear terms by planning experiments–curve fitting, step response analysis, noise analysis);

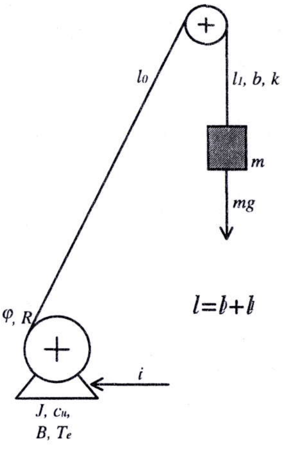
**Linear control** (LQ control based on linearization around fixed operating point, pole assignment control, PID control)

**Nonlinear control** (generalized exact linearization, constrained control, anti-windup PID control)

**Fuzzy control, Neural control, Adaptive control.**

### 6.4 Mine Lift with Rigid/Flexible Suspension






$$m\frac{d^2l}{dt^2}+b\frac{dl}{dt}+k\frac{l-l_0-R\varphi}{l}=mg$$

$$J\frac{d^2\varphi}{dt^2}+B\frac{d\varphi}{dt}=c_u i-kR\frac{l-l_0-R\varphi}{l}$$

This equipment is result of the own development. Wireless communication with the cab enables to decrease friction and damping of the cab oscillations. It gives possibility to change suspension (rigid, or flexible with

different elasticity).
The duration of transient responses is in the range of s.
Not yet available on Internet due to the safety problems and the not solved problems of the on line identification.

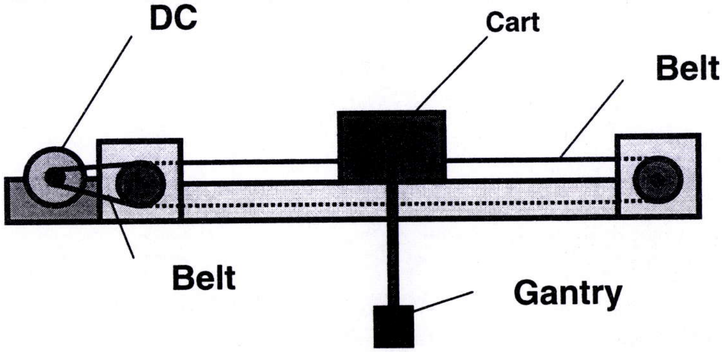
6.4.1 Measured and Controlled Signals

- cab position (incremental decoder), drive angle (incremental decoder), drive velocity (tacho) and DC motor current,
- voltage controlled DC motor.

6.4.2 Task Solved

**Manual control** (not easy practicable – motivation for the automatic control)
**Identification of a marginally stable nonlinear system** (analytical identification combined with experimental identification - identification of particular nonlinear terms by planning experiments– curve fitting, step response analysis requiring closed loop stabilization of the starting position, measurement & quantization noise analysis);
**Linear control** (LQ control based on linearization around fixed operating point)
**Nonlinear** generalized exact linearization, constrained control, anti-windup PID control)
**Fuzzy control, Neural control**.

### 6.5 Gantry Crane Model with Several Modifications




The professional product (Amira, Germany) required modification of the gantry angle measurement (dead zone). It is equipped with the I/O converters card compatible with the Matlab/Simulink environment. The duration of transient responses is in the

$$\ddot{x}_c = \frac{F + m_r \sin\varphi(g\cos\varphi + l\dot{\varphi}^2)}{m_c + m_r \sin^2\varphi}$$

$$\ddot{\varphi} = \frac{-\ddot{x}_c \cos\varphi}{l} - \frac{g\sin\varphi}{l}$$

x – cart position;
$\varphi$ - gantry angle

range of s. In order to be online accessible via Internet, it needs to be equipped with a safety control and positioning system.

6.5.1 Measured and Controlled Signals

- card position and pendulum angle (incremental decoders), lengths of the suspension
- gantry position in two axes (horizontal, vertical) controlled via DC motors

6.5.2 Task Solved

**Manual control** (not easy practicable – motivation for the automatic control)
**Identification of a marginally stable nonlinear system** (analytical identification combined with experimental identification - identification of particular nonlinear terms by planning experiments– curve fitting, step response analysis requiring closed loop stabilization of the starting position, measurement & quantization noise analysis);
**Linear control** (LQ pendulum control based on linearization around fixed operating point, cart control with removed or flexibly fixed load hinge)
**Nonlinear control** (generalized exact linearization, constrained control, anti-windup PID control)
**Fuzzy control, Neural control**.

# 7 Conclusions

Development or purchase of appropriate equipment represents just the 1st step in offering experimental way of learning. In the next phases, many other problems have to be solved, as e.g.

- organization and administration of the access to the experiments,
- establishing database of case studies dealing with particular experiments,
- development of specialized software,
- corresponding staff development,
- development and running of resources necessary for individual student work (library, information technology, equipment),
- student support and guidance,
- provision of complementary equipment necessary for plant identification,
- organization of international events like summer schools, etc.

Briefly we could conclude by the statement that introduction of experiments has fully changed activities of our working group.

## Acknowledgments

This work was supported by the Slovak Scientific Grant Agency under the grant No. 1/7621/20.

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