

PROCESS MODELS FOR A NEW CONTROL EDUCATION LABORATORY

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Abstract: Process models for a new self-contained laboratory for training and education of control have been designed. Models are considered to be connected to the MATLAB through universal data acquisition instrument called CTRL. The latter was developed together with the models to enable realization of control experiments in a comfortable computer processing and visualization environment. The paper focuses on a short conceptual description of each model, together with the expected educational benefits. Furthermore, at the final part of the paper, the CTRL instrument is shortly presented. *Copyright©2005 IFAC*

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1. INTRODUCTION

Control engineering is a wide range area that absorbs innovative approaches and methods (Dorf and Bishop 1998). Study of engineering systems requires to use a multidisciplinary approach. It often crosses the traditional boundaries of engineering. Control engineers have to understand engineering and scientific principles together with

their application, experience and technological significance. It includes knowledge of modelling real processes as a prerequisite in design of control systems (Bissell 1998, Horáček 2000, Kheir 1996). Excellent laboratory systems are essential for the communication of this knowledge; both as a mechanism and as an example to expand engineering experience and an intuitive grasp of effective methods (P.L. Lee and Shastri 2003). Experimental modelling in laboratories presents the most difficulties when first encountered with plenty of practical aspects (Jovan and Petrovic 1996).

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Looking through the proceedings of IFAC Symposia concerning control education, one may witness many changes but also similarities in building control laboratories. There are rapid changes in software tools used for process monitoring, simulation, control algorithm design and implementation. More and more university and research laboratories use MATLAB. Much effort has been spent in many labs over the world developing real-time software for enabling MATLAB to work in real time and to have an access to the real world (Horáček 2000).

What does not change much, are the laboratory experiments or the experimental models in particular. Moreover, although the present industrial controllers mostly use PI or PID control algorithms, experimental modelling gives chance for introduction of recent results into real practice. Experimental models allow to train modern control methods safely, and are not too far from real conditions. However, getting an experimental model should be either long-term or expensive thing.

Therefore, the authors have concatenated their potential by setting up an open scientific-research consortium. Principal task of each consortium member is to design, develop and make one physical model that reflects the reality of real processes given by static and dynamic characteristics. Contribution of this arrangement can be seen in substantial savings of both time and money and in obtaining more experimental models at the same time. Developed models allow us to introduce modern self-contained laboratories in locations where the authors work.

In literature (P.L. Lee and Shastri 2003, Horáček 2000) or on Web pages (e.g. www.mathworks.com), numerous physical models suitable for the experimental work are described. This paper attempts to extend this collection and to report on new process models which relate to the long term practical experience of the authors in the design of control systems. Models, which are proposed, are derived from real situations and laying stress on educational aspects and uses of new information technologies. The set of models consists of:

- (1) Hydro-pneumatic MIMO (multiple input multiple output) model for training of control at different time delays and levels of coupling.
- (2) Rotation speed-control model with an elastic clutch and load for training of mechanical systems control.
- (3) Ball & Ellipse model for training of control with multiple inputs and one output.
- (4) Temperature-air MIMO model appropriate for studying and testing air conditioning systems.

- (5) Time delay model for training of process control with variable time delays.

All models are lightweight, compact and hence easily portable. Manipulated and controlled variables are provided via unified electrical signals. Models are autonomous in the sense they need no another energy medium except the ordinary electric power. Although the educational and industrial aspects are stressed, an emphasis on safety during training is included as well as an impact to economic consequences for the possibility of less investment.

To make control experiments, the models need to be connected to a computer program like MATLAB. For doing this, the original portable instrument called CTRL is developed. The CTRL instrument is an autonomous mini-sized microcontroller-based interface. It allows any computer or workstation able to measure and/or transfer d-c electrical signals via the RS 232 communication line or USB port to function correctly.

In order to facilitate real-time control of the models in MATLAB, software modules were proposed for measurement and transfer of electrical signals in the MATLAB environment. The advantage of the CTRL against other acquisition cards is that it can be connected to any portable PC without changing anything inside the computer. Since computer-independent, this organization benefits from more flexible laboratory equipment.

The paper is organized as follows. Sections 2–6 introduction of the experimental models together with discussing their educational benefits. Section 7 refers to the data acquisition unit CTRL. Conclusions are given in Section 8.

2. HYDRO-PNEUMATIC MODEL

This model is shown in Fig. 1. In contrast to pure hydraulic systems (Horáček 2000), it combines both hydraulic and pneumatic components in order to stress coupling between water tanks. The model consists of four water tanks, grouped in two couples. In every section, water is pumped through a valve into the upper tank, flows into the lower tank through an orifice and from here through a second orifice back into the reservoir. Air spaces above the water are connected together by pneumatic volumes and valves with the possibility to release air to the atmosphere. These pneumatic connections create a cross coupling between each section.

System properties and structure may be manually changed by the size of the orifices and by the valves in the pneumatic loops. The water levels in all tanks are measured by difference in

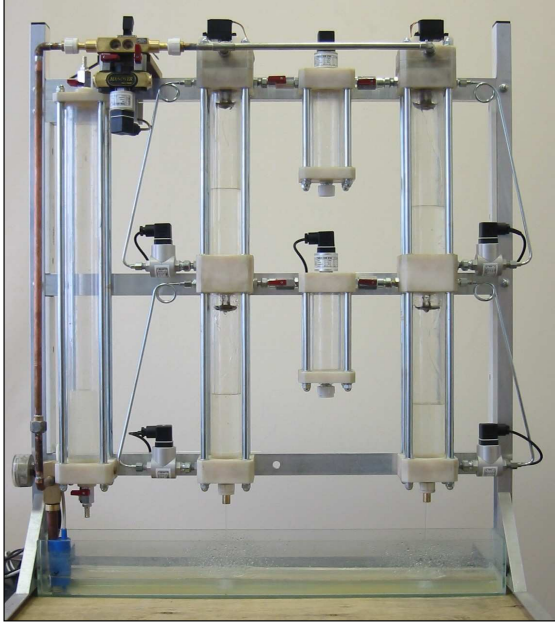


Fig. 1. Hydro-pneumatic model.

pressure sensors. Pressures in pneumatic volumes, atmospheric pressure and inlet water pressure are measured too.

The model as an object of control is sketched in Fig. 2. It has two outputs (water levels in lower tanks - y_1, y_2) and three inputs (two valves for water inlets u_1, u_2 and pump power u_3). Blocks are organized as follows:

- G_1 – left-side upper water tank,
- G_2 – right-side upper water tank,
- G_3 – left-side bottom water tank,
- G_4 – right-side bottom water tank,
- G_5 – upper pneumatic volume,
- G_6 – bottom pneumatic volume,
- G_7 – air chamber.

All blocks represent nonlinear behavior associated with nonlinear differential equations of the first order. Seven measured state variables (4 levels - $x_1, x_2, x_3 = y_1, x_4 = y_2$ and 3 pressures x_5, x_6, x_7) are available for identification and control purposes. Relatively complicated inner structure of this system may be interpreted as two symmetrical coupling loops with derivative behavior. Interactions between both hydraulic parts are presented in transition states only. They are eliminated in the stable conditions.

It gives a variety of control possibilities for this model, for example:

- SISO control loops such as the control of level in lower tanks, left or right, with open pneumatic loops.
- MIMO control (three inputs, two outputs) of levels in lower tanks, where the pneumatic loops are connected.

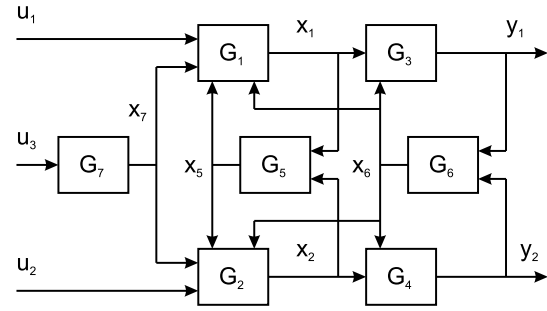


Fig. 2. Block diagram of the hydro-pneumatic system.

3. ROTATION SPEED-CONTROL MODEL

This model is shown in Fig. 3. It enables rotation speed control of an industrial DC-motor with the load and elastic clutch. It consists of a DC-motor with load and measuring devices. A dynamo, that can be brought into an effect, creates the load disturbance. The latter is signalized by lights. The load is connected with the DC-motor by a clutch which can introduce elastic or coupling muff. There are possibilities to use two types of elastic clutches that differ in their static characteristics: a clutch with a watch spiral or with a rubber cable. The measure device is the speedometer which is calibrated by an incremental speed sensor.

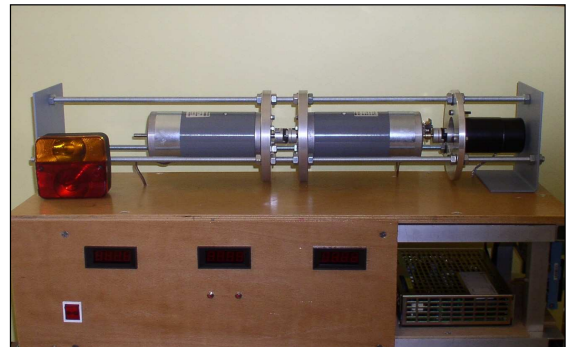


Fig. 3. Rotation speed-control model.

The system has approximately linear characteristics in the operating range with oscillating movement in output if the elastic clutch is used, or the output is over damped, if the coupling muff is used. A block diagram of this system for the control purposes is shown in Fig. 4.

Pedagogical facilities for control methods training with this plant include:

- Creating a mathematical model of the plant based on the physical analysis. Verification of this model.
- Design of rotation speed or position controller (PID, state-space and fuzzy control).
- Control and measure from a WWW based remote computer.

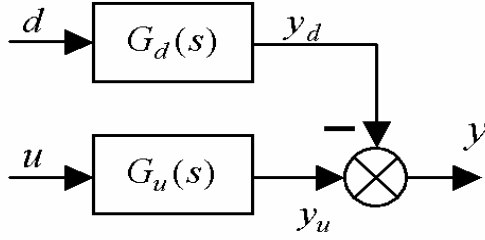


Fig. 4. A block scheme of the Rotation speed-control model.

4. BALL & ELLIPSE

The laboratory model Ball & Ellipse is shown in Fig. 5 in the form, which is lightweight, compact and hence easily portable. It consists of an ellipse pivoted in its center in such a way, that its tilt can be controlled in two perpendicular directions. Two servomotors are used for tilting the ellipse. A steel ball rolls freely on two parallel tensioned resistance wires, which have an elliptic contour. The ball works as the sliding contact of a potentiometer. The position of the metal ball is sensed by a transducer.

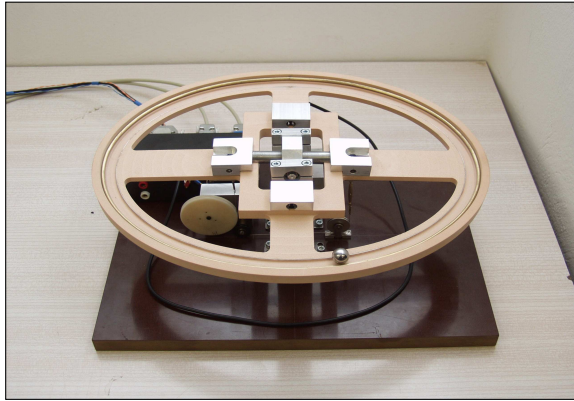


Fig. 5. Ball & Ellipse model.

From a control point of view, the Ball & Ellipse system is a dynamic system with two inputs and one output as shown in Fig. 6. A basic goal is to control positions of the ball rolling on the ellipse railway. In fact, it relates to control problems associated with unstable non-linear systems. A wide range of control experiments include:

- Direct derivation of a mathematical model of the apparatus using physical laws.
- Linearization and simplification of the mathematical model for given control purposes.
- System identification and model validation.
- Stabilization and trajectory tracking of the ball position via PID controller design.
- LQ/LQG controller design based on a state-space model.

- Fuzzy, adaptive or nonlinear controller design.



Fig. 6. Ball & Ellipse block configuration.

5. TEMPERATURE AIR MODEL

The model called Hot-Air Aggregate (HAA) is a physical model of air-conditioning as shown in Fig. 7. There are the source of heat air (the small bulb) with quick dynamic response and two ventilators as the sources of air flow. Together in the model, there are six transducers measuring the temperature of hot air flow at three different positions from the bulb, two flow meters (propeller turbine and thermo anemometer) for volume flow measurement and one photo resistor sensor of bulb luminance.

The HAA model is a dynamic system with two inputs and two outputs. The two basic controlled inputs (action values) are the power of the bulb and other one power to the main fan (ventilator). Measured outputs there are a temperature from one of the temperature transducers (by this position the time delay of the system is changed) by one of flow meters (with quick or slow response). As a disturbance it can use the secondary fan with opposite air flow direction (the complementary action value).

This HAA model is used to train:

- MIMO control (temperature and air flow) with adjusted disturbances.
- Robustness of control via changes in working point. It influences time constants of transient responses (typical control task takes 2 or 3 minutes).
- Nonlinear control given by built in nonlinearities.

6. TIME DELAY MODEL

The model of a heat-interchanging system (shown in Fig. 8) serves for training of systems with a time delay. The time delay is realized by measuring the temperature of the media at several places in the interconnecting pipeline. Maximal value of the time delay is 7 minutes.

The model contains a safe hot water source with electric heating and thermostat-based regulation in the range between 30 and 85°C. Hot water is transported by a variable-speed pump into the interconnecting pipeline ending in a heat exchanger.

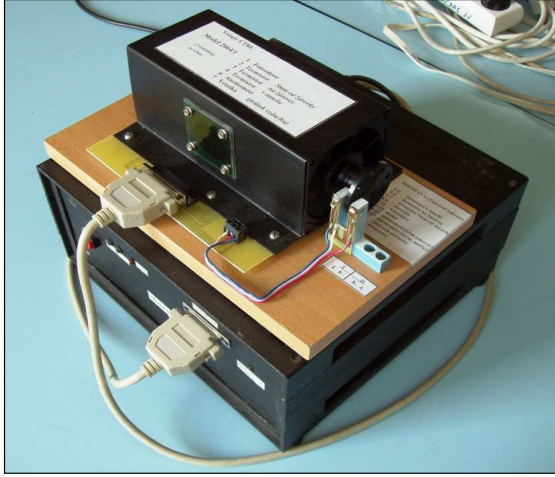


Fig. 7. Temperature air model of air-conditioning.

The pipeline is connected through an intercepting valve, where the flow is divided between the pipeline and a reversing coupler. The pipeline itself is composed of several meanders where it is possible to place thermometers and thus to obtain various values of the time delay. The time delay can also be affected by changing the speed of the pump and position of the valve. The heat exchanger makes it possible to establish variable heat dissipation. It creates a disturbance.



Fig. 8. Time delay model.

A principal scheme of the plant with the time delay setting possibilities and general transfer function is shown in Fig. 9. Algorithms for identification and control of the temperature in defined location (indicating different time delays) are well trained using this model. It mainly includes:

- Control of processes with substantial time delays.
- Robustness of control for variable time delays.
- Identification of time delays.

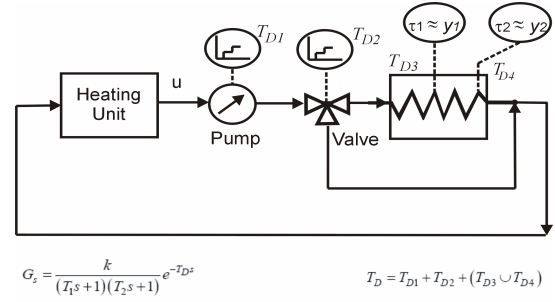


Fig. 9. Time delay model by a block scheme.

7. CTRL REAL-TIME INTERFACE

The CTRL instrument (as shown in Fig. 10) is a portable autonomous microcontroller-based interface giving any computer or workstation the possibility of measuring and/or transferring d-c electrical signals via a serial line or the USB port. Since placed in a current serial connector, no cable is needed for the communication with a computer.

The CTRL instrument has the following parameters:

- Analogue inputs/outputs: 4/2 (0–10V range, 9 bits resolution, output current in the range 0 to 50mA)
- Logical inputs/outputs: 4/4
- Serial input/output: RS 232 or USB
- Direct connection of an 12V relay
- Power supply: AC/DC adapter 12V/300mA
- Dimensions: 60 × 55 × 15mm

The following CTRL scripts have been developed to support the basic data acquisition functions in MATLAB 6 or 7 environment:

Script	Mean
open_port()	Opens port
get_y()	Measures inputs
set_u()	Realizes outputs
set_t()	Turns on real time
close_port()	Turns off port

They enable MATLAB users to provide current control tasks with above models in the real time. For example, it includes the measurement of step responses, SISO and/or MIMO control activities, comparative studies of different controller settings etc.

Illustrate the use of the above CTRL scripts in a typical user's script which realizes the measurement of a model transient response. For doing this, the user's MATLAB script could be as follows:

```
% opens serial port com1
s=open_port('COM1');
% sets sampling period in seconds
set_t(s,period);
% sets voltage value (0-10V)
```

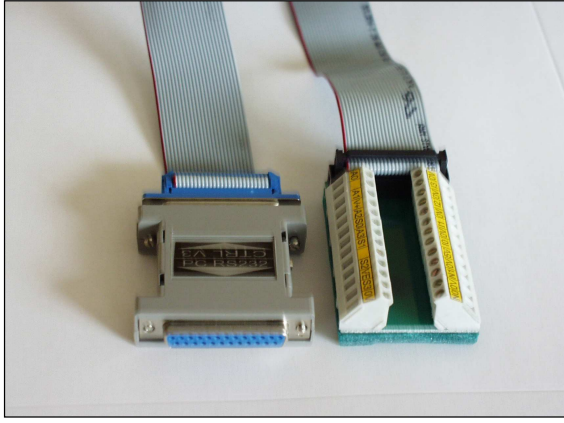



Fig. 10. Data acquisition interface CTRL V3.

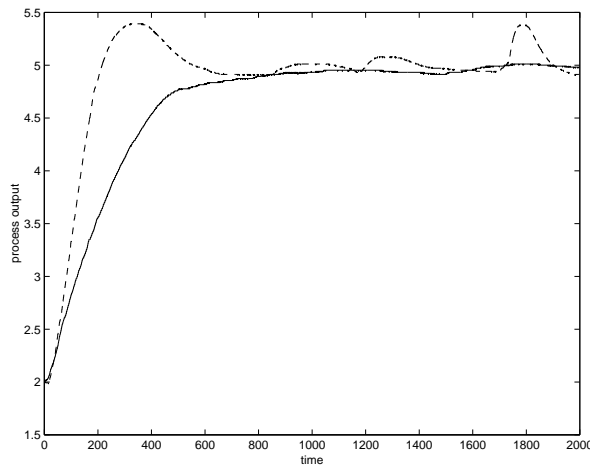


Fig. 11. PI regulation responses: Ziegler–Nichols tuning (broken line), balanced tuning (solid line).

```
% on the CTRL output (0 or 1)
set_u(s,output,value);
% measures values of the
% transient response from input (0-3)
for i=1:number_of_samples
    y[i]=get_y(s,input);
end
% makes a plot
plot(i,y)
% closes port
close_port(s);
```

It offers the powerful way for the realization of practical tasks including all types of control even with logical relationships. Moreover, MATLAB graphical tools allow us to visualize all measured and/or computed responses as it is shown in Fig. 11. Here, the CTRL was used to compare different PI controllers at setpoint step in the water tanks model. There are responses for Ziegler–Nichols tuning (broken line) and the balanced tuning (solid line).

8. CONCLUSIONS

In this paper, the authors inform about a set of new experimental models including the hydro–pneumatic model, rotation speed–control model, ball & ellipse model, temperature air model and time delay model. An emphasis has been stressed to connect them to the MATLAB environment. A low cost unit called CTRL was developed for this purpose.

It is always a task for a user to balance time spent in manufacturing, the setup in the university workshop and money spent for buying the equipment ready for use (Horáček 2000). The authors have solved this problem by composing a consortium in which each member develops an original experimental model with the ability to produce this model for the other consortium members and also for other potential users.

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