PROCESS CONTROL TEACHING ON LABORATORY PLANT SUPPORTED BY INTELLIGENT TUTORING SYSTEM

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Abstract

Conception, design and application of laboratory plant for training of students of chemical engineering in automatic control are presented.
Training programme is composed on such a way that all control methods are considered from classical to modern based on artificial intelligence conception. Finally, original intelligent tutoring system is applied and distance learning is introduced.

1. Introduction

Over the past three decades control scientist and educators presented various learning scenarios using laboratory and pilot plants as efficient support in training process modeling and control (Colwell *et. al*, 2002). We designed and built our very first laboratory plant in the 70's. Since then the plant has been continuously redesigned and teaching control methods made better equally from the methodical and pedagogical viewpoint. New knowledge as well as hardware, measuring and control devices have been introduced and finally our laboratory exercises have been gradually turned in a versatile training ground for development of system thinking and integration of theoretical and experimental work (Bozicevic, 1984, 1990).

For example, in the 80's we introduced teaching and training in linguistic modeling and fuzzy process control. In the 90's, originally arranged educational laboratory plant is considered to be the basis for more effective training of the students of chemical engineering in advanced process control using Honeywell UMC 800 controller. Then, laboratory research has been broadening with application of neural network for modeling and process control (Blazina & Bolf, 1997; Bolf *et al.* 1990). Genetic algorithms have been applied in tuning controller's parameters (Grundler & Bozicevic, 1997) while knowledge based control method is still in development.

In parallel since late 80's we have studied and developed original intelligent tutoring system, TEx-Sys. Now we are refining the intelligent hypermedial authoring shell (Stankov & Bozicevic, 1997), which will finally be basis of our advanced educational tool for distance laboratory education (Lab-TEx-Sys).

TEx-Sys is structured as system model, which allows building of a universal educational tool for teaching control methods in natural, social and technical system. This paper presents a part of the research as well as the experiences gained in work with students.

2. Laboratory Set-up

The laboratory plant consists of a cascade of two heat exchangers. In the first stage (Process 1) the feeding liquid is heated to a temperature, $\boldsymbol{T_{T1}}$, by maintenance of heat balance between heat generated by build-in heater $\boldsymbol{H_{T1}}$, and heat taken away by cooling spiral/jacket. Level sensor, $\boldsymbol{L_{T1}}$, serves for liquid level control.

The second stage is a suitably designed hot bath, *T-2*, with heater, $\boldsymbol{H_{T2}}$, in which the spiral is immersed. Liquid flows through spiral where is heated and maintained at constant value of the temperature, $\boldsymbol{T_{S2o}}$, which is measured on the exit of the spiral.

The temperatures $\boldsymbol{T_{T1}}$ and $\boldsymbol{T_{S2o}}$ represent main controlled variables of Process 1 and 2, respectively. The task is strict maintained of the $\boldsymbol{T_{S2o}}$ within the given limits. The powers of the heaters in the first tank, $\boldsymbol{P_{HT1}}$, the second tank, $\boldsymbol{P_{HT2}}$, and flow of cooling water through the jacket (spiral), $\boldsymbol{q_{J1}}$, serve as manipulated variables.
The system comprises five control loops: two temperature loops, level loop, and two flow loops.

The variations in the flow of liquid caused by variable pressure in next process stage, *p(t)*, is considered as a main source of disturbance. Other sources of disturbances are flow and temperature variations in the feeding liquid stream and variations in ambient temperature.

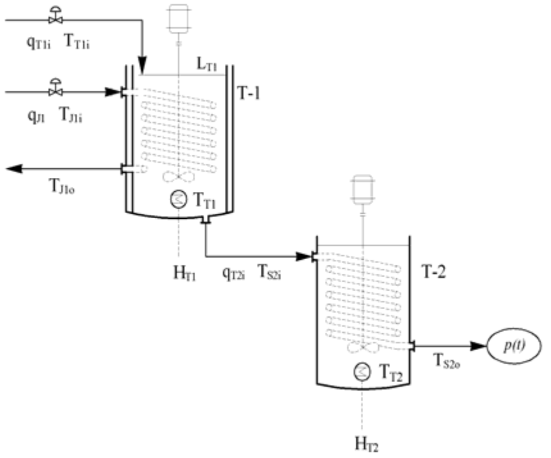

Figure 1: *The two-stage heat exchange process in laboratory teaching plant.*

3. Conception of the training programme

3.1. Introduction

The aim of the laboratory plant encompassed:

a) mathematical modeling and identification;
b) Traditional methods of process control (feedback, cascade, split, feedforward control);
c) computer-based measurement and control;
d) fuzzy and neural network-based process control;
e) Computer aided training using TEx-Sys.

The flexible organization of the learning units allows flexible teaching organization, depending on the purpose and goal of the presented teaching programme.

3.2 Mathematical modeling

The dynamical mathematical model of the process is presented by input-output structure diagram (Appendix), the relations between the input and the output variable as well as the influences of the parameter is studied in the details. Then the results of computer simulation (MATLAB), with results of experimental research are being compared and studied. The steady-state process model serves for the definition of set points and specification of control tasks. A special lesson is dedicated to comparative evaluation of transfer functions, state space and real time model of the plant. Aside of the lessons on modeling and simulation and experimental verification of the model, also selected identification tasks are considered.

3.3 Traditional process control

The exercises cover well known lessons in classical control theory, which generations of chemical engineering students have been taught, continuous and on–off control are studied in details. Then, we have shifted emphasis, on digital control theory and in early eighties first computer control was applied.

Two feedback control loops shown in Figure 2 are the principal subjects of the study and exercise during first learning unit. They are characterized by different process dynamics and therefore they are very suitable in training of the controller tuning. There are many various tasks within this learning unit, but the design of the linear control system and its stability are treated especially in detail.
The investigation of complex behaviour of the whole process is considered too with the aim to maintain the overall process goal. The conception of hierarchical control is introduced and applied, but the detail study is a part of second learning unit which contains exercises in digital computer control.

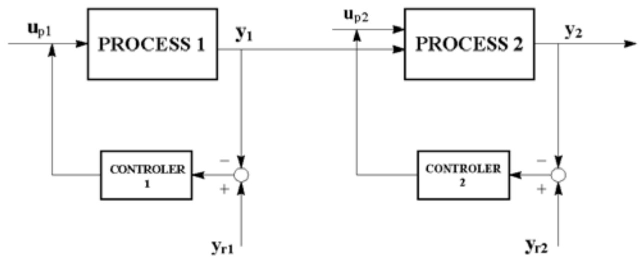

Figure 2: *Traditional process control scheme.*

3.4 Fuzzy process control

In the eighties training in the conventional automatic control has been gradually enriched with fuzzy control theory (Bozicevic, 1987). At the beginning the aim was to familiarize students with the basic concept and procedures of the newly developed linguistic modeling and to show how the fuzzy set theory enables the usage of vagueness and uncertainly, nonprecise, ill-defined concepts and operation with these in mathematically strict sense. The synthesis and the analysis of fuzzy feedback control were introduced and finally fuzzy feedforward and composite control (Stipanicev & Bozicevic, 1986).
Student selected within working group play the role of the operator, he/she performs the operator's tasks and become experienced enough, so that his control actions may serve for the definition of fuzzy control algorithm. Then the students study and test three control strategies:

1) the operator uses the error as information and adjusts the power below or above certain value;
2) the operator uses the error as information and corrects the temperature by changing the electric power;
3) the operator uses the error and the rate of change of error to effect a change of electric power.

For each strategy students have to develop the rules, and than set up the algorithm. The performance of fuzzy process control is compared with the performance of an ordinary PI controller and PID controller tuned during the first learning unit, naturally only as a rough illustration of relative performance.

The fuzzy feedforward and fuzzy composite control are also taught. The control procedures are developed by means of the fuzzy relational model of process. The disturbances in pressure, $p_L(t)$, are taken as a disturbance which gives ground for feedforward control actions. The following particular exercises are considered:

a) modeling of the first process and evaluation of a fuzzy model suitable for feedforward control application;
b) synthesis of fuzzy feedforward as well as fuzzy feedforward – feedback controller;
c) development of the software and the analysis of the performance compared with the classical feedback and composite control.

3.5 Neural network-based control

Use of the neural networks offers effective means of handling complex, nonlinear and uncertain processes. Basically, students are thought how to design and apply neural network control through following task (Bolf *et al.*, 1997):

a) Direct network control; the neural network is trained as a controller and the controller output is determined directly.
b) Inverse network control; training a neural network as an "inverse" model of a process, and the process inputs necessary to produce desired process outputs (setpoints) are being predicted.
c) Coordinated control supported by neural-network based model of the process.

In the Figure 3 an approach to neural network-based control task, coordinated model-based control is shown.

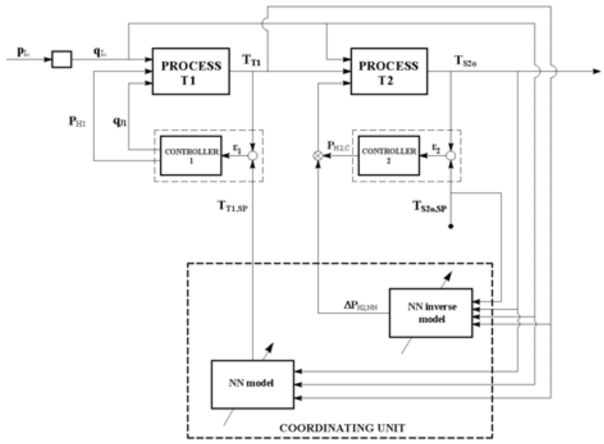

Figure 3: *Coordinated control supported by neural-network based model*

3.6. Application of Honeywell UMC-800 Controller

In the beginning PC was used for a process control and the students had opportunity to learn on the data acquisition, and development of necessary software. Recently, Honeywell universal multiloop controller (UMC800) is installed. It enables teaching student in industry standards in control. UMC-800 is also considered to serve as basis for more effective training of the students of chemical engineering in advanced process control.

4. Intelligent hypermedial authoring shell as a tool for process control teaching

System model of education shown (Bozicevic *et al.*, 1990) in Figure 4 is use as basis for development of tutoring system and its gradual transformation in intelligent hypermedial authoring shell named TEx-Sys. It is adjusted to both teachers and students. The control function in TEx-Sys is based on: (i) measurement and diagnostics of student knowledge, (ii) determination difference between actual student knowledge and the one described in the referent model (iii) evaluation of student knowledge with recommendations for future work. Recently, we have designed Lab-TEx-Sys which permits integration of our laboratory plant measuring and control units with Lab-TEx-Sys and is start-up point for distance learning.

4.1. Background

Student knowledge level or achieved level of domain knowledge serves as manageable variable for the actual instruction unit of domain knowledge. The referent value is defined through: (1) the goals and tasks of *the subject matter*, which need to be understood; and (2) *the "good" student model* based on evaluation criteria which implicate the cognition of specified student knowledge level.

The computer tutor, as a replacement for a “human” tutor, acts as a feedback in the instruction system, which has the tasks of: (1) monitoring, i.e. measuring and diagnosing the student knowledge, (2) determining differences between actual student knowledge and the referent model, (3) managing activities’ states, and (4) the new knowledge transfer or remediation.

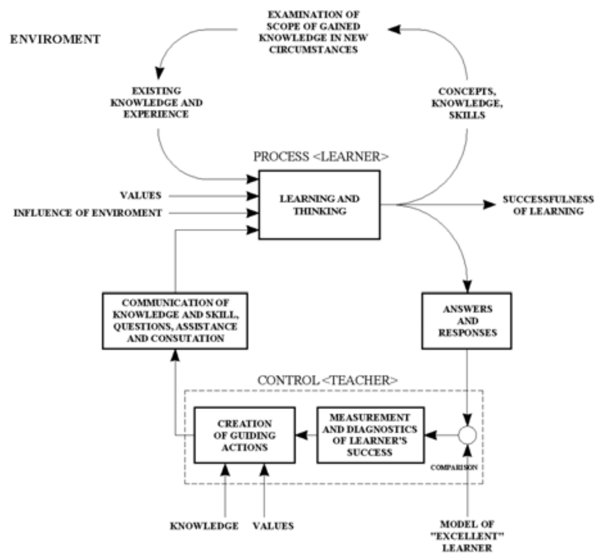

Figure 4: *Model of teaching system which serves as the basis of TEx-Sys*

TEx-Sys is structured into the following modules, as is shown in Figure 5:

- *Login*: legalization of work on the system;
- *T-Expert* (Developing module) building the base of freely chosen domain knowledge (for teachers, and in particular cases for students, too);
- *Learning and Teaching* (Learning &Teaching module) of freely chosen domain knowledge (for students);
- *Testing* (Testing module) evaluation of a student's knowledge within a teaching scenario, according to Piaget's theory of "guided free play" (Sugerman, 1978) and combinations of scenarios of teaching by "articulated experts" and "dialogues of divided initiatives"(Carbonel, 1970);
- *Evaluation* (Evaluation module) access to the achieved results of learning and teaching (for teachers and for students too);
- *Quiz* (Quiz module) is implementation of the test, in which a student gets set of questions with attached answers. The student solves the test by marking answers he/she assumes to be correct. After the student solves the test, he/she gets a mark (according to his answers) and a recommendation for additional learning about the domain knowledge, if the system concludes that he/she isn’t acquainted with them based on evaluating his/her answers (for students).

The formalism for knowledge presentation in TEx-Sys is based on semantic networks with frame and production rules. The basic components of TEx-Sys semantic networks are nodes and links. Nodes are used for presentation of domain knowledge objects, while links show relations among objects. Beside nodes and links, the system supports properties and frames (attributes and respective values), along with property inheritance. The system heavily relies on modern supporting technologies, such as multimedia, with the following structure attributes: picture, animation, slides, hypertextual description and URL address are also available.

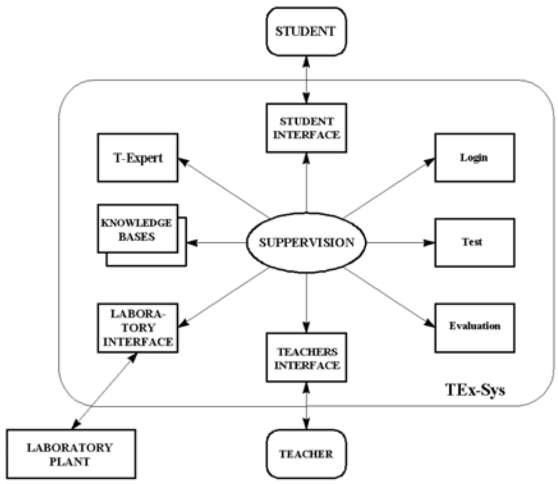

Figure 5*: The structure of Lab-TEx-Sys*

Using program module D*eveloping* the knowledge base <*Two-stage heat exchanger*> has been developed. It has the following structure: 176 nodes, 181 links, 43 structure attributes. In their work students use *Learning and Teaching* module designed for acquiring necessary knowledge, whereas module *Quiz* is used for knowledge testing.

4.2. Learning and teaching with TEx-Sys using knowledge base

The knowledge base is structured to allow use of semantic kinds, which TEx-Sys has, for knowledge presentation. In their preparation for work on TEx-Sys, students have to previously learn: (1) knowledge formalization with semantic networks; (2) semantic kinds in TEx-Sys; (3) work with program modules of TEx-Sys. In the learning and teaching process students go through the following stages:

- Understanding of the domain knowledge decomposition;

- Login to the TEx-Sys;
- Learning and teaching with the knowledge base;
- Knowledge testing and evaluation with recommendations for future work;
- The knowledge base <*Two-Stage Heat Exchanger*> is used for teaching process control and gathering experience with experimental laboratory plant.

5. Conclusion

An original program of laboratory exercise for student of chemical engineering is presented as an example of training approach. Students solve the basic process control tasks, develop and analyze process model and than apply various control methods, study stability and finally have a test of the acquired knowledge. During the laboratory work the students are expected to master each learning unit in the following steps:

- introductory discussion on necessary knowledge for training and understanding and scheduling experimental tasks;
- deriving of the functional tasks, study of process, measurements, control structure, etc.
- experimentation,
- analysis and discussion of the results,
- reviewing of the experiments, reporting.

Intelligent tutoring supports training in laboratory. The knowledge base build in the TEx-Sys system framework is designed in this purpose. Students have possibility to test their knowledge much more concisely than in the traditional way.

The students that had used TEx-Sys were very enthusiastic, especially with:

- the possibility to take a lecture at any given time and place,
- the benefit of learning through multimedia approaches
- quiz for testing their knowledge, which they accept as very objective evaluation.

The system provides all students in the chemical engineering course with exposure to an industrial-like control problem. It enables final year students to gather experience through two-semester projects. The experiences from the application of this system open a number of ways for future work.

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***Appendix**: Structural scheme of the two-stage heat exchanger with emphasize on interactions*