Experimental Teaching of Process Control Principles Supported by Intelligent Tutoring System

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Abstract

The method of process control teaching of chemical engineering students and engineering by means of cybernetic model of a system, supported by the experimental plant developed in a laboratory, is presented. The process has been designed and adapted so it would enable teaching in both traditional and modern control methods.
The method is then considered as a basis for development of intelligent tutoring system, that comprises an original interactive system, while its author shell has been built with a knowledge base on process control methods and experimental research.

1. Introduction

Control scientist, educators, and chemical engineering alike have over the past three decades presented numerous papers discussing various learning scenarios, and presenting designs, advantages as well as disadvantages of different laboratory plant and pilot plants for student's training process modeling and control (Colwell et. al, 2002). Our very first laboratory plant was designed and built in the 70's, and since then the plant has been continuously redesigned, and new measuring and control techniques have been applied. We have continuously followed the progress in control science and gained experience in interdisciplinary laboratory training students of chemical engineering. Except of for the experimental training during which practical illustration of theoretical lessons have been provided, our laboratory exercises have been gradually turned in a workshop for development of systems thinking and integration of knowledge through experimental work.
In the 80's the syllabi of our subjects have been enriched with new contents: linguistic modeling and fuzzy process control. Therefore, we decided to develop a new, more advanced laboratory exercises, which will enable a versatile application of computer aided experimentation, and comparison of conventional and fuzzy process control. The originally arranged educational laboratory plant (Bozicevic, 1988 & 1990) is considered to be the basis for more effective instruction the students of chemical engineering in advanced process control.

By rapid developing methods based on genetic algorithms methods and neural networks in the 90's, the laboratory research has been broaden with application of neural network for modeling and process control (Blazina & Bolf, 1997; Bolf *et al*. 1999). Developing our own software applications supported all of the researches.

Researchers dealing with information and communication technology in education and instruction, as well as guided learning and teaching process, support our approach. They have developed and are now refining the intelligent hypermedial authoring shell Tutor Expert System (TEx-Sys) (Stankov, 1997). TEx-Sys has properties of an isomorphic system model, for it allows building of an intelligent tutoring system aimed to learning and teaching of occurrences and their acting in nature, techniques and society. TEx-Sys is applied for learning and teaching of process control on the laboratory heat exchanger at the Faculty of Chemical Engineering, University of Zagreb. Three courses are supported: Process Measurement and Control (V^{th} and VI^{th} semester), Mathematical Modeling (VII^{th} semester), and Chemical Engineering Practicum (VII^{th} and $VIII^{th}$ semester). This paper presents a part of the researches as well as the experiences gained in work with students.

2. Laboratory Set-up

The laboratory two-stage heat exchange process is shown on Figure 1. It consists of a cascade of two heat exchangers. The first stage (Process 1) comprise stirring tank, *T-1,* where the feeding liquid enters, and where it is heated to a temperature, T_{T1} , build-in heater, H_{T1}, cooling spiral/jacket. Ultrasonic level sensor and transmitter, L_{T1}, serves for the liquid level control in cascade with control valve of feeding liquid. The second stage is a suitably designed hot bath , *T-2*, with heater, H_{T2}, in which the spiral is immersed. Liquid flows through spiral where is heated to the temperature, T_{S2o} **,** that is measured on the exit of the spiral.

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

The variation in the flow of liquid caused by variable pressure, $p(t)$, is the main source of disturbance. Other sources of disturbances are flow and temperature variations in the feeding liquid stream and ambient temperature variations. They all affect on overall material and heat balance of the system.

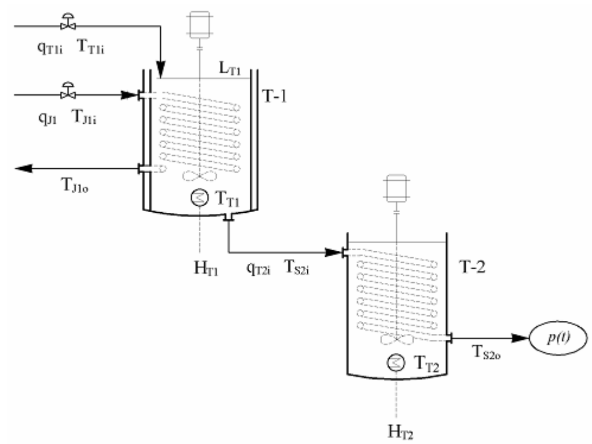

Figure 1: The two-stage heat exchange process in laboratory teaching plant.

3. Study of the process modeling and control

The development of the system encompassed the following steps:

a) Mathematical modeling and system identification;
b) Traditional methods of process control (feedback, cascade, split, feedforward control) supported by computer-based measurement and control;
c) Fuzzy and neural network-based process control;
d) Development of knowledge base and computer aided instructions 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.

3.1 Traditional methods of process control

The mathematical model of the process is based on theoretical description of the heat balances and experimental knowledge. The causal relations between the input and the output variable as well as the influences of the parameter are developed.

The results of computer simulation (MATLAB), and the experimental research are being compared and studied, taking into consideration variations of input variables, set points and parameters. Sensitivity and interactions have also been investigated. 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, selected identification tasks are introduced.

Two feedback control loops shown on Figure 2. serve to exercise the tuning of controller, and also there are many various task within this learning unit. Feedback and feedforward control tasks are introduced first, then cascade control and split control. The investigation of dynamical behavior of the integral process is considered with the aim to maintain the overall process control goal. The conception of coordinated control is introduced and applied.

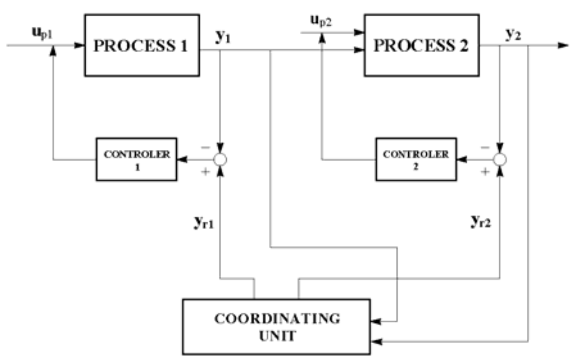

Figure 2: Traditional control units applied on the laboratory plant connected by coordinating unit

The standard PC-computer was used for a process control by means of data acquisition boards, while the necessary software has been developed. Finally, PC-based control is modernized during the last two years by using Honeywell universal multiloop controller (UMC800) that enables teaching of process control supported by industry standards in control.

3.2 Fuzzy and neural network process control

Since the mid-eighties, the conventional syllabus in automatic control has been gradually enriched with fuzzy control theory. 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 uncertainty, nonprecise, ill-defined concepts and operation with these in mathematically strict sense. The synthesis and the analysis of fuzzy feedback control were introduced (Mamdani & Assilian, 1975), and finally fuzzy feedforward and composite control (Stipanicev & Bozicevic, 1986).

The control procedures are developed by means of the fuzzy relational model of process. The disturbances in *p(t)* are considered as the basic information for feedforward control actions .

Use of the neural networks offers effective means of handling complexity, nonlinearity and uncertainty in chemical processes. It also gives a contribution to the teaching and training capabilities of the laboratory teaching plant.

After studied various approaches to the neural network applications in process control two categories are adapted for teaching students how to apply neural network control (Bolf *et al*., 1999). Using these approaches, a neural network is incorporated into a system in either a nonadaptive or adaptive manner

3.3 Schedule of the laboratory activities

During the laboratory work the students are expected to go through the following steps:

- Discussion on the learning unit, introducing the main task and scheduled experimental tasks, essential knowledge that should be learned
- Deriving of the functional tasks, study of process, measurements, control structure, etc.
- Experimental research
- Analysis and discussion on the results
- Reviewing of the experiments, reporting.

Within preparation stage of laboratory experimenting students use the TEx-Sys system. It helps them to learn and tutor using the knowledge bases designed in the TEx-Sys system framework. On the TEx-Sys system students have possibility to test their knowledge much more widely than in the traditional preparation, thus being able to perform all the necessary activities in executing experimental research on the actual laboratory plant.

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

Considering modern information and communication technology and its implementation in the instruction system as well as implementation of the principles of system science, didactic principles, principles of individualized teaching, methods and techniques of artificial intelligence we have projected and built an 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 differences between actual student knowledge and the one described in the referent model, and (iii) evaluation of student knowledge with recommendations for future work.

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) 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.

TEx-Sys is structured into the following modules, as is shown on Figure 3:

- *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, which can be correct or incorrect. 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 learning more about some entities of domain knowledge, if the system concludes that he/she isn't acquainted with them, by 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. TEx-Sys uses following predefined semantic primitives for links: IS_A, SUBCLASS, A_KIND_OF, INSTANCE, and PART_OF. Besides that, TEx-Sys uses a semantic primitive labeled PROPERTY for showing properties, as well as a diagram for encoding knowledge in packages named FRAMES, Figure 6; both features are incorporated in the semantic network with a search capability. A FRAME is usually assigned to an object; the object has an optional SLOT, i.e. an attribute set (<Slot>) and the respective values (<Filler>). Finally, there is also a possibility for the user (either the teacher or the students) to generate other semantic primitives for domain knowledge formalization and their storing in the knowledge base.

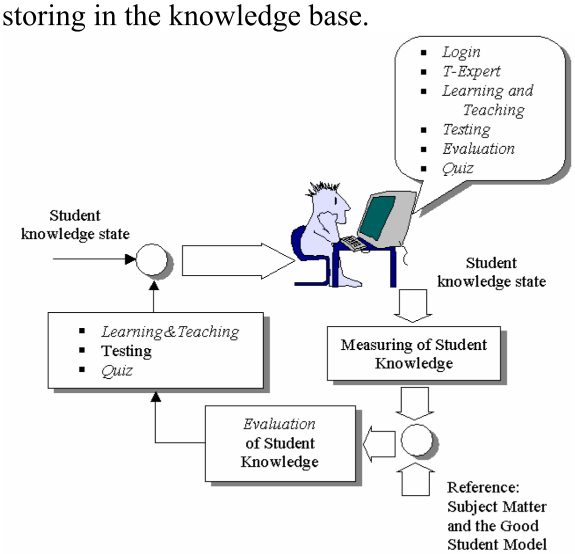

Figure 3: Interaction of TEx-Sys module in student knowledge and skills acquisition procedure

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

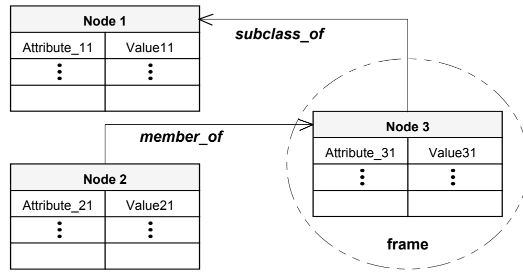

Figure 4: *Structure of semantic network with frames in the TEx-Sys*

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 students of chemical engineering in process control and gathering experience with experimental laboratory plant. The screenshot of object <*Heat Exchange Process*> in the knowledge base <*Two-stage heat exchanger*> is shown on Figure 5. The knowledge base comprises all necessary knowledge for the process control with detailed explanation of control loops and their elements, control principles, rules and tips for tuning. The text is supported by ilustrations and simulations. The base is constantly being built up using modern conception in the control theory field.

The students that had used it 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

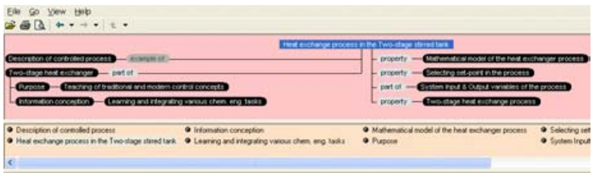

Figure 5: Structure of the object "Heat Exchange process in the Two-stage stirred tank"

5. Conclusion

The laboratory plant for training students of chemical engineering in system thinking, and process control through exercises in mathematical and linguistic modeling, classical and modern (fuzzy and neural network-based) process control is presented. Synthesis of student knowledge and development of students' self-reliance should be emphasized as a particular result.

The knowledge base <*Two-stage heat exchanger*> within TEx-Sys is being used at the Faculty of Chemical Engineering and Technology in the chemical engineering courses as a teaching support. 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 system is accesible for students through computer classroom or through CD version. The results achieved in training students and development of their skills in research on particular tasks have shown that the students are able to acquire and test their knowledge individually, aided by the intelligent tutoring system. The system also enables the students to broaden their knowledge aside from the regular Chemical Engineering curriculum. The experiences from the application of this system open a number of ways for future work.

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