

A Laboratory Course on Real-Time Control for Food Engineers*

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In this paper, we describe a control laboratory course as a teaching aid during the training of undergraduate food engineering students. This approach facilitates the understanding of the subject matter (Application of Artificial Intelligent (AI) in food processing) introducing a first-hand experience at implementing real-time intelligent control. Students execute a series of laboratory exercises, for a variety of processes, implementing fuzzy control and neural networks.

INTRODUCTION

IN ADDRESSING the need for bringing intelligent control research into the curriculum, we have developed a laboratory course accessible to students interested in theory and application of intelligent control. Students exiting the sequence are equipped with the ability to design controllers and estimation/identification techniques using fuzzy logic, neural networks and general rule-based systems.

Good interaction between control theory and real-time systems opens up for a unified approach and more integrated algorithms. Several authors are trying to join simulation and real-time control such that the students can explore new technology, experiment flexible approaches and show that the simulation experience is transferable to real-life problems, see [1] and [2]. A good paper that dealt with design of control and real-time system is [3].

There exist numerous control laboratories around the world for the instruction of classical, modern and intelligent control techniques; the interested reader is referred to [4] and [5]. In particular, the laboratory demonstrates several key attributes of fuzzy control, including control design with limited conventional modeling exercises, comparative analysis with conventional controllers need/advantages of adaptation for fuzzy controllers. Moreover, we go beyond the treatment of only fuzzy control by providing the opportunity to implement neural networks for control.

This paper describes the new control laboratory course at AFVI Training Center, Yaracuy, Venezuela.

Students execute a series of laboratory exercises, for different processes, implementing fuzzy control, adaptive fuzzy control, and other intelligent control techniques, with a particular focus on fuzzy control. Fully instrumented independent equipment in the pilot plant emphasizes several sensing and actuation technologies. Both senior undergraduates and graduate students can take the course and coupled with research. The Real-Time Toolbox®, for use with MATLAB® and Simulink®, produces code directly from Simulink models and automatically builds programs that can be run in a variety of environments, including real-time systems and standalone simulations.

The pedagogical objectives of the integration of real-time control experiments in the teaching of Application of Artificial Intelligent (AI) in food processing subjects may be summarized as follows:

- Initially every topic is discussed theoretically.
- Subsequently an appropriated simulation is used to verify and complement the discussed theory.
- When the students integrate theory and simulation then they go to the lab and control of pasteurizer using the technique discussed before.
- The three points mentioned earlier are repeated for all main topic in artificial intelligent: fuzzy control, neural networks and neuro-fuzzy.

The simulations, which are used during lectures, are also making available to the students for study purposes. The benefits of this approach are summarized by:

- Time is used very effectively in a lecture (Application of Artificial Intelligent (AI) in food processing).
- Time consuming, sometimes incomprehensible

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explications of difficult concepts are replaced by simulations and real-time experiments

- When students do sensitivity analyses of their models, a thorough theoretical feel for the subject matter is attained, leading to an enhanced understanding of the relevant concepts.

COURSE OVERVIEW

The laboratory course is preceded by a one-year course 'Application of Artificial Intelligent (AI) in food processing'. The attendance is mandatory for the laboratory course. An overview of the lecture is depicted below:

- Introduction to AI and application in food processing
- The Mathematics of Fuzzy Control
- Design Parameters of Fuzzy Controllers
- Nonlinear Fuzzy Control
- Introduction to Neural networks
- Neural networks for control
- Neuro- Fuzzy Adaptive Networks
- Introduction to MATLAB (computer lab) in parallel with the theory in class

The laboratory course uses to start in the semester 2 and it includes 3 experiments; however, in the future, the number of experiments will increase with the incorporation of new equipments to the laboratory

In the computer lab, the students simulate and analyze several plants and control systems. In contrast to the laboratory experiments, the

simulation is cheap, easy and free of risk. During the computer lab practice, the specific objectives are:

- *Plant parameters:* the student defines the more important parameters of the plant. Several examples are given.
- *Control structure:* The students will evaluate the all possible structure from classical (PI, PID) until advanced structure (Fuzzy and NN).
- *Possible disturbances and noise:* evaluation of disturbances and noises using unrealistic amplification of high frequencies and how they can be reduced or cancelled.

At this point, the simulation can be replaced with a laboratory experiment. The students are familiar with MATLAB software and they can work with the Real Toolbox and create their own control systems.

Laboratory equipment

The equipment to be used is a pasteurization unit as depicted in Fig. 1 (source Alfa Laval). The plate heat exchanger (PHE) consists of a pack of stainless steel plates clamped in a frame. The plates are corrugated in a pattern designed to increase the flow turbulence of the medium and the product. The pasteurizer is divided into five sections. Sections 4 and 2 are for regeneration, section 1 and section 3 for heating and section 5 for cooling. First, the raw milk at a concentration of 4.1% in carbohydrates enters section 4 of the PHE at a temperature of 2.0°C. It is preheated to a temperature of 60.5°C by the outgoing pasteurized milk, which as a result is reduced to a temperature of

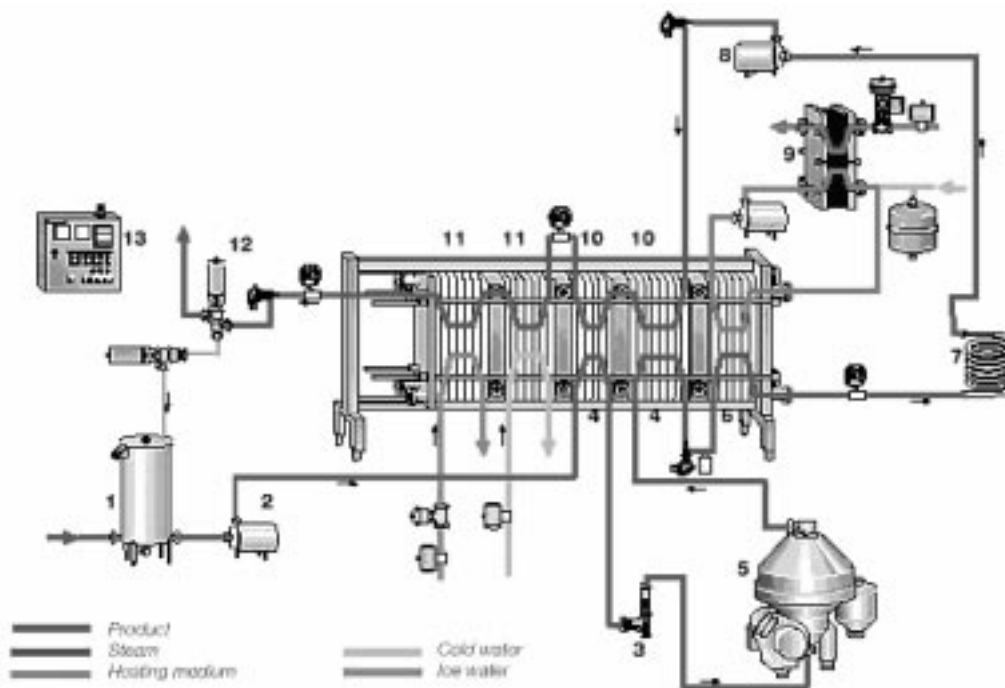


Fig. 1. The pasteurizer.

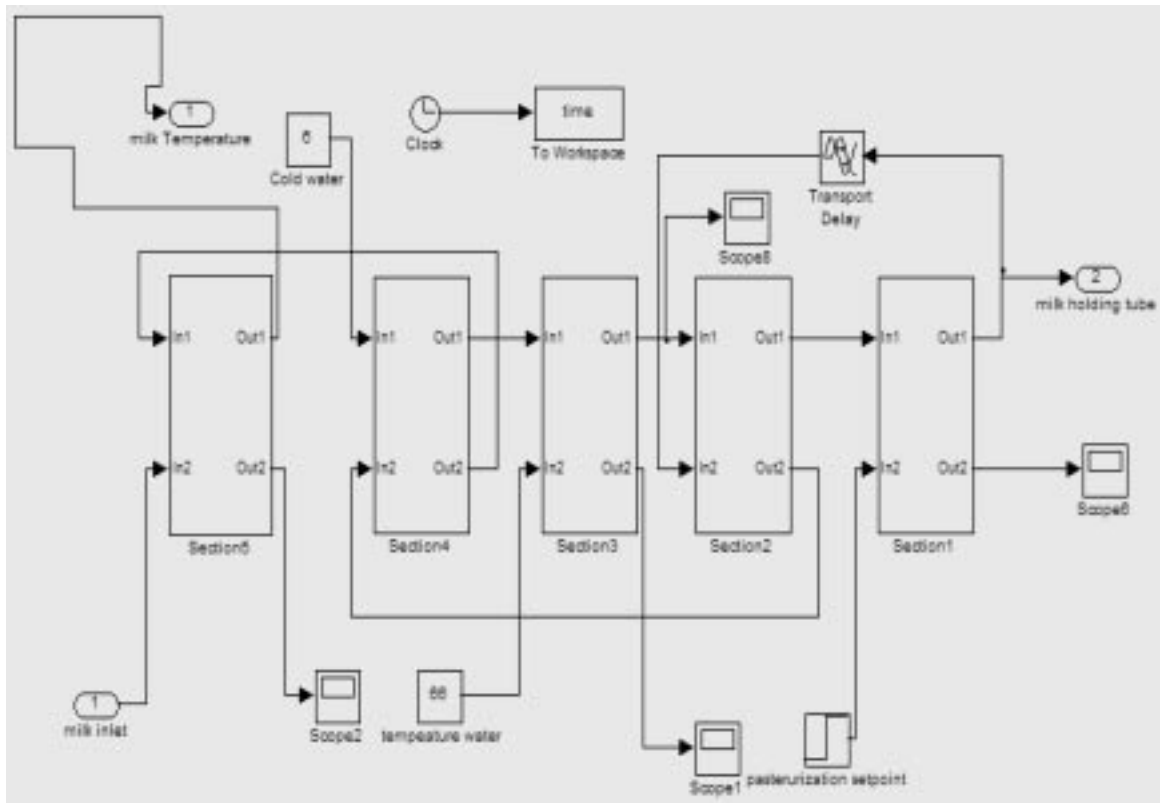


Fig. 2. Pasteurizer model.

11.5°C. Passing this section, the milk now at a temperature of 60.5°C enters section 3 where its temperature increases to 64.5°C using hot water. The milk is homogenized to a concentration of 3.5% in carbohydrates before the next section. In Section 2, the milk is preheated to a temperature of 73.0°C using the already pasteurized milk as hot medium. The milk is brought to the pasteurization temperature in section 1 (75.0°C) using hot water

at around 77°C. The milk is kept in the holding tube for 15 s before being cooled using the incoming cold milk in sections 4 and section 2. Finally, the milk is chilled to a temperature 1.0°C using propylene glycol as refrigerant at a temperature of -0.5°C. The hot water flow is 0.08 m³ s⁻¹ and milk flow is 0.1 m³ s⁻¹

The implementation is presented the three following steps:

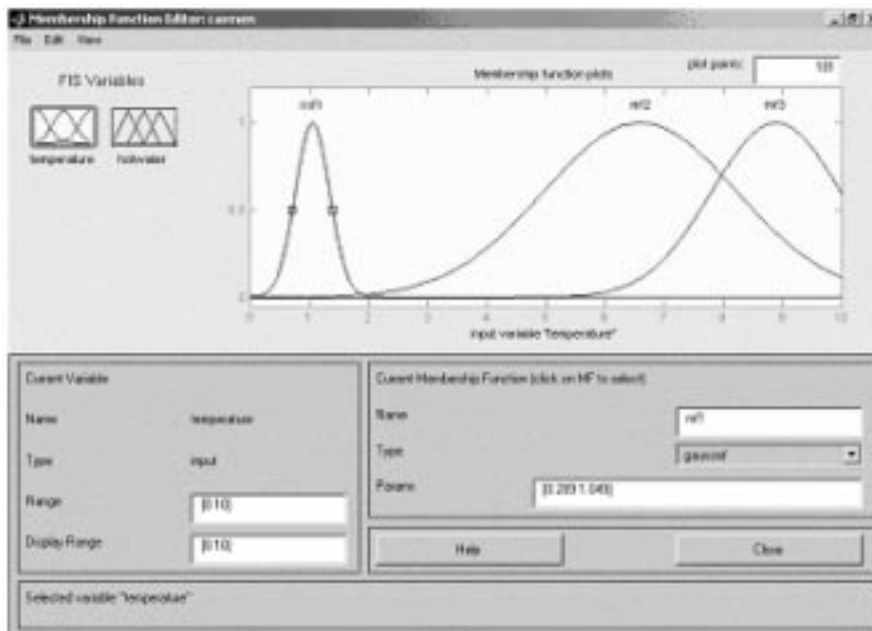


Fig. 3. Membership function editor.

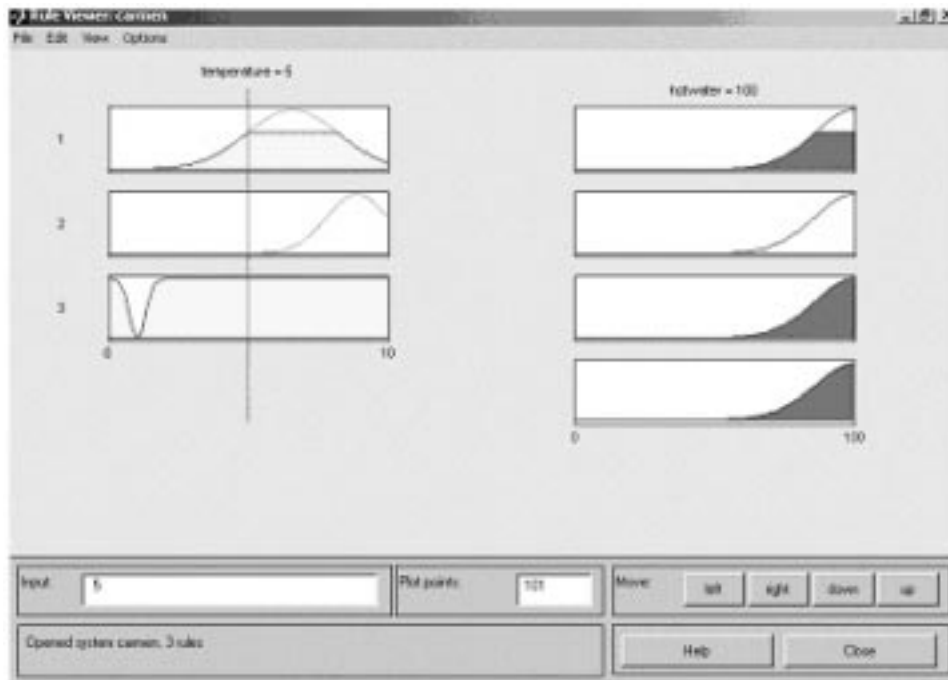


Fig. 4. Inference engine rule editor.

1. The simple simulation is the first step where the system is usually developed. MATLAB/Simulink should be used as shown in the Fig. 2.
2. Real-Time communication between MATLAB-Simulink and the real process controlled. In this case MATLAB receives real data from the process output and send action values to the real process input. An AD612 acquisition card is used.
3. Direct implementation of algorithm from simulation tool.

Specific problems of the setup and making accurate control difficult were reduced; including accurate sensing of the liquid flow (in the presence of turbulence due to the pumping action) and dead-band non-linearity in the DC pumps.

Experiment 1

The goal of the experiment 1 is to introduce Fuzzy Interactive System (FIS) tool and to become familiar with the language. In this case we use the MATLAB tool FIS editor invoked by typing 'fuzzy' at the MATLAB prompt. On the next few lines the different aspects of the FIS Editor are shown. Effectively this is a rather more sophisticated rule and membership function generator:

1. Open the FIS editor.
2. Create a new system with two inputs and one output.
3. Edit the Membership functions as desired.
4. Create the inference engine.
5. Save the system.
6. Export the system to the MATLAB Workspace—this is necessary so that Simulink can use the fuzzy block.

- *Membership function editor:* The students must define each membership function for every parameter. They must also ensure that the units and scale of the inputs and outputs match what is actually required (i.e. the hot water output to the pasteurization unit is from 0 to 6.6 m³/h). An example for SISO system is shown in the Fig. 3.
- *Inference engine rule editor:* The Inference Engine Rule Editor shows the combination of the different rules; an example is depicted in the Fig. 4. Once again the students must ensure that there are not possible input combinations that are not covered by the rule base.
- *Fuzzy rule output viewer:* There is a viewing tool to look at the output as a function of the two input variables. If this graph has any big jumps in it then it is likely not to work well. There must be a smooth path from every starting point to the center.

The second part of Experiment 1 is to introduce the students in the neural networks editor. The NN editor allows to training the NN of an easy manner. The MATLAB screen editor is shown in the Fig. 5.

Training data is given to the students at computer lab. The students simulate different scenarios using different neural networks, error, number of layers, etc. Afterward, the students evaluate the best neural network and it will be implemented over the pasteurization unit in the Experiment 3.

Experiment 2

Many students have some experience with pasteurization unit control. There is no need to explain why and how to pasteurize. The first is to select physically sensible controller inputs from the

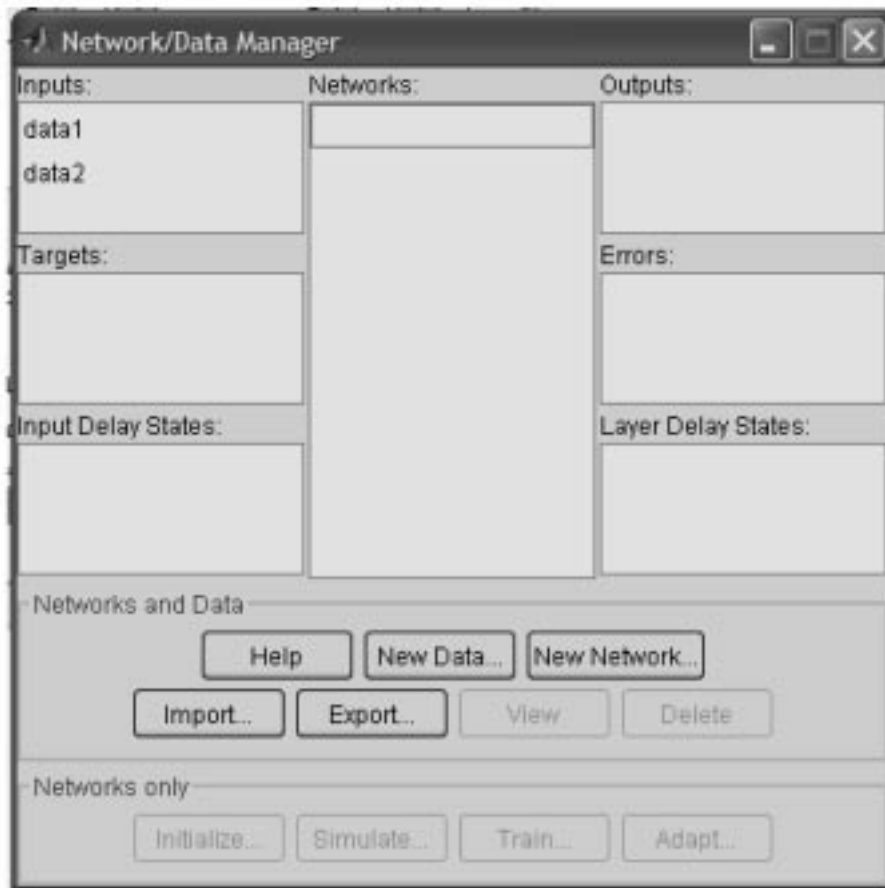


Fig. 5. Neural network editor.

measured parameters. The following variables can be chosen:

- inlet milk temperature;
- hot water temperature;
- hot water flow;
- inlet milk flow.

As output of the system, the following variables can be considered:

- outlet milk output (pasteurization);
- outlet milk output (cooling section 3).

All variables are well suited as fuzzy controller input/output. The practical knowledge of the process can be incorporated into the fuzzy controller design. With suitable membership functions and rules the input/output characteristics of the fuzzy controller can be tuned to compensate the temperature problems.

As mentioned earlier, the fuzzy controller is implemented over the pasteurizer using Real-Time toolbox and MATLAB/Simulink. A noise filter is installed in the system. When the pasteurization process is carried out with hot water, the noise and the disturbance should be tried carefully because the changes of pressures can amplify the signals quickly.

The Real Time Toolbox is an interface to real-time and data acquisition capabilities of your

computer. Based on a simple real-time kernel and drivers for popular data acquisition hardware, it enables to acquire external data with accurate timing. The version 3.0 was used and the following conditions were considered:

1. Sampling frequencies 50 kHz.
2. Speed is limited only by your data acquisition hardware.
3. 4 independent timers, 5 input and 5 output channels.
4. On-line data processing by discrete polynomial filters.

Examples of the response of the pasteurization unit using the model and Real time toolbox are illustrated in Figs 6 and 7.

The objective of this control experiment is keeping the outlet-pasteurized milk at 75°C and the outlet-cooled milk at 3°C. In the assessment sheet given to the students, see Table 1, the students should write as the objective was achieved describing the type of fuzzy membership function, rules, defuzzification etc.

Experiment 3

Since we want to be able to determine an appropriate and interpretable behavior within a small number of simulation runs, we decided to split the implementation process in two main steps.

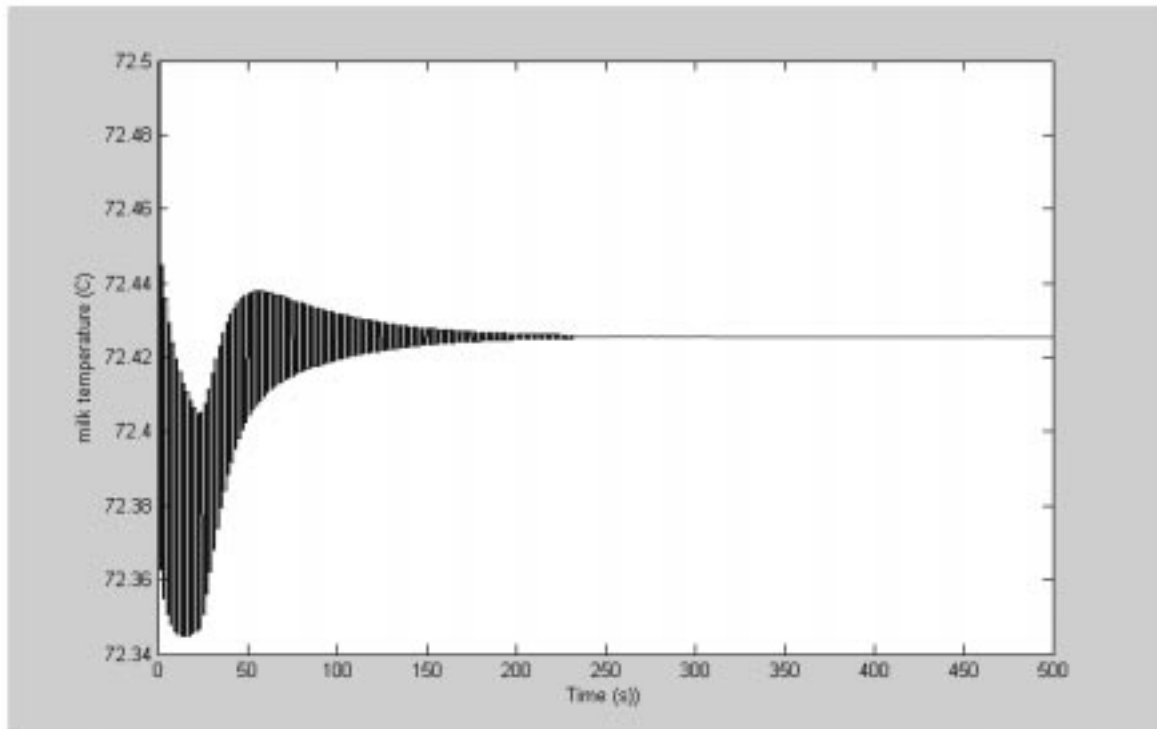


Fig. 6. Response of the pasteurizer at 30% step in the hot water.

During the first step, the NN was taught and optimized using a model of the real plant, see Fig. 1. Because of the differences between the real plant and the model used, the NN controller will not be able to control the real plant appropriately in most cases. Therefore, a second learning step will be necessary. In the second step, the NN is

optimized by use of the real plant. During the on-line training phase, noise is added to the reference signal and the conditions are saved using data files. Thus, an appropriate working NN can be found with less experimental (and time) effort on the real plant. Besides, the risk of a damage of the real plant is reduced.

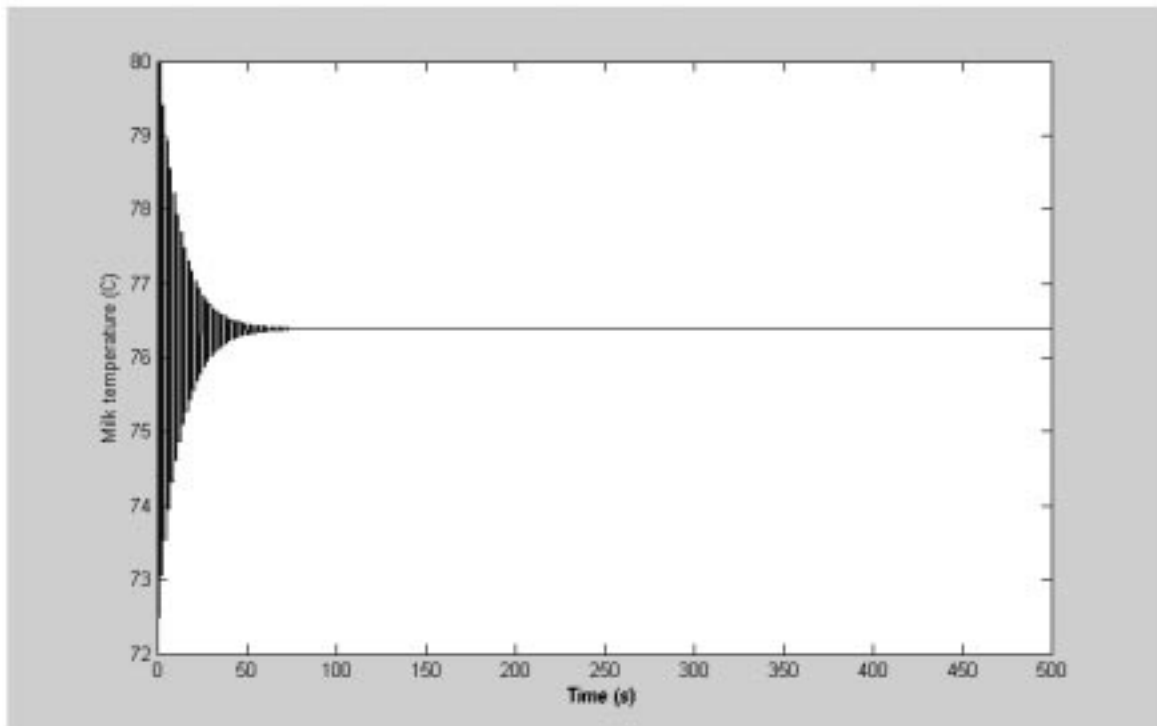


Fig. 7. Response of the pasteurizer at 10% step in the hot water.

Table 1. Assessment sheet. Experiment 2

Subject	Minimum requirements
Linguistic variables	Selection and naming of variables Range Membership functions Defuzzification method
Rules	Performance of rules AND or OR method Sensibility Define the surface
Disturbances	Types of disturbances Effect of defuzzification method over disturbance compensation Noise

When the NN is optimized, the students fill another assessment sheet as in Experiment 2. The assessment sheet for experiment 3 is a little different. The format is illustrated below.

Examples of the response of the pasteurization unit using the model and Real time toolbox are illustrated in Figs 8 and 9.

At end of the experiments, the students will provide to the supervisor a report describing as the NN has worked and a diskette with the NN used.

EXTENSION TO DISTANCE LEARNING

While the students can take these classes from a remote location they still have to come onto the Center for the laboratory practice. This restriction can be overcome by allowing students to access the pasteurization unit from a distance location using Internet or web-control.

The Internet offers many advantages over other technologies, which makes it the medium of choice. Nowadays, almost every household has a telephone line, which makes a potential Internet connection. With the Internet, the laboratory can easily be expanded to distance learning. Last semester, the web-control was installed. The students took field data and tested their models. Our first steps allow us monitoring the unit however not control; distancing the user from the local experiment keeping the same degree of

interactivity; but they cannot modify the control system. The reason is to avoid wrong manipulation of the variables or tuning parameters that can produce damages over the system. The friendly interface was made using a graphical user interface (GUI) and students can evaluate the response and modify the milk temperature setpoint only if it is necessary. We have ongoing effort to develop new experiments to distance learning. For the next academic year, the 20% total marks will be a coursework based on field data using web-control system.

STUDENT FEEDBACK

The students generally responded very positively to the lecture and lecture-laboratory courses. In spring 2003, the laboratory started as optional course with 9 students. For autumn 2003, 12 students took the lab (30 students registered in Application of Artificial Intelligent (AI) in food processing). Finally, spring 2004, all students were registered in the laboratory; they were separated into 6 groups. Actually, the laboratory is a mandatory course and the students prepare small projects applying artificial intelligent techniques. Two papers have been submitted on some projects done in the lab. They liked the laboratory lectures and felt that they helped see how they could apply the methods to even more complex industrial applications. Several students made direct use of the intelligent control course and laboratory in their Final Projects.

CONCLUSION

The paper depicted a sequence of exercises accessible to undergraduate students interested in theory and application of intelligent control. The sequence ran with great success for first time in early 2003, with 9 students in the laboratory course. Students are equipped with the ability to design controllers and estimation/identification techniques using fuzzy logic and NN.

Table 2. Assessment sheet, Experiment 3

Subject	Minimum requirements
On-line training (the students have to specify the minimum requirement for each type of NN used)	Set of data used Noise (type and frequency) Optimal NN and why Errors Number of layer used
Disturbances	Types of disturbances Effect of defuzzification method over disturbance compensation Noise
Comparison	Compare fuzzy vs NN and evaluate: response, settling time, offset, time in implementation.

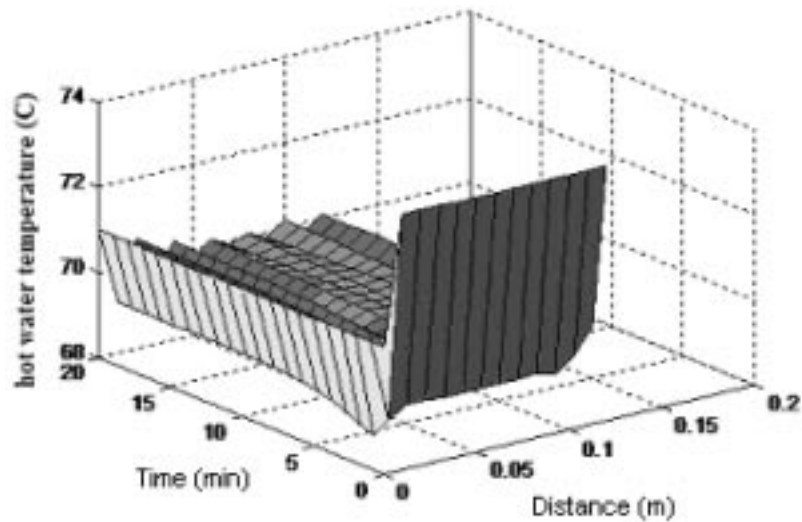


Fig. 8. Response of the hot water temperature at 30% inlet milk temperature step.

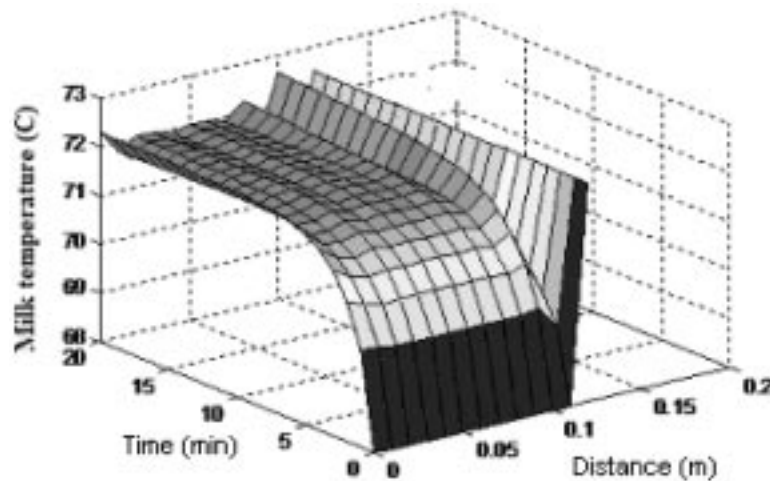


Fig. 9. Response of the outlet pasteurized milk temperature at 30% hot water step.

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