Implementation of an Undergraduate Intelligent Control Laboratory[1]

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Abstract

Recently, the author has been awarded a grant by National Science Foundation (NSF) in order to develop an interdisciplinary intelligent control laboratory. The objective of the laboratory is to substantially improve the instructional capability of undergraduate instruction in intelligent systems analysis and design. The project addresses simple, robust, and effective implementation of soft computing techniques for several industrial applications including Servo Systems, Heat Trainers, and Visual Component Inspection Stations. The development is carried out through the adaptation of innovative industrial design techniques, incorporation of real-time sensory interfacing and other applicable industrial advances, which have been already utilized in several manufacturing industries such as Motorola Inc. The implementation of an undergraduate intelligent system laboratory can serve as a model for other institution in the nation.

I. Introduction

During the last four decades, many model based control techniques have been proposed by the researchers. However, most of these methods have often been subordinated to the development of mathematical theories that dealt with over-idealized issues bearing little relation to practice. In reality, many processes are model free systems where their mathematical representations are not necessarily available.

On the other hand, during the last decade, the critical links between complexity, ambiguity, robustness, and performance of various processes have become increasingly evident. This may explain the dominant role of emerging "intelligent systems" in recent years [1]. However, the definition of intelligent systems is a function of expectations and the status of present knowledge: Perhaps the "intelligent systems" of today are the "classical systems" of tomorrow.

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From a broad perspective, intelligent systems underlie what is called "soft computing"[2]-[4]. The principal partners in soft computational methodologies are fuzzy logic, neural network computing, generic algorithms and probabilistic reasoning. Furthermore, these methods are, for the most part, complementary to each other. The integration of these methodologies provides a foundation for the conceptual design and deployment of intelligent systems.

The concept of intelligent systems was first introduced nearly two decades ago [9]. Despite its significance and applicability to various processes, the control community paid no substantial attention to such an approach. During the last five years, intelligent control has emerged as one of the most active and fruitful areas of research and development within the spectrum of engineering disciplines with a variety of industrial applications [5]-[15]. It is, therefore, essential that all students who take a control course have the opportunity to obtain hands-on experience with typical applications of intelligent systems. The construction of an intelligent control laboratory permits Florida Atlantic University (FAU) to accomplish such a goal. Furthermore, the development of the laboratory can serve as a model for other institution in the nation.

II. Goals and Objectives of the Project

The objective of the new laboratory is to substantially improve the instructional capability of undergraduate instruction in intelligent systems analysis and design. Students from electrical engineering, mechanical engineering, ocean engineering and computer science and engineering will benefit from the education principles provided by the laboratory instruction. Presently, there is neither an intelligent system laboratory nor a soft-computing laboratory available to the students in these disciplines at Florida Atlantic University.

The connection between theory and practice has always been one of the most difficult lessons to teach in engineering. This problem is particularly accentuated in control theory where there is a high level of abstraction. The proposed project is intended to substantially improve the capability of undergraduate instruction related to recent trends and developments in intelligent control technology. The developed laboratory is utilized to supplement an introductory intelligent system course as well as four other courses. In addition, the new laboratory provides a vehicle for the development of intelligent Systems projects for EE and CE and ME students. The project has accomplished the following goals and objectives:

 * *To familiarize the student with the implementation of Intelligent Systems;*
 * *To demonstrate the flexibility of microprocessors in the design and implementation of FL and NN controllers;*
 * *To introduce the use of test set ups emerging in academic and industrial control communities, but not yet utilized in the undergraduate university environment;*
 * *To evaluate NN and FL controller performances of fairly complicated linear or nonlinear systems;*
 * *Provide a vehicle for the development of undergraduate senior projects related to intelligent systems.*

III. Intelligent System Laboratory and Related Curriculum

Construction of instructional laboratories with modern equipment has always been given top priority at the College of Engineering at FAU. Presently, there are six undergraduate laboratories in Electrical Engineering including electronics, instrumentation, communication, digital signal processing, electromagnetic, and digital control.

The introductory intelligent control course (EEL 4930) which is the primary course for the developed laboratory consists of instruction in the design and implementation of intelligent control techniques as an emerging technology for various industrial applications. Presently, the course is a 3 credit senior elective course and normally enrolls 25 students per semester from various departments in the college. It covers topics related to learning, approximate reasoning and decision-making capabilities of intelligent systems using Neural Networks (NN), Fuzzy Logic (FL) and Neuro-fuzzy. The lab experiments are an integrated part of the course.

In addition, undergraduate students can enroll for Introduction to Neural Networks (CAP 5615), Control II (EEL 5634), Digital Control (EEL 5653) and Industrial Automation (EML 4356) as elective courses in the area of controls and automation. Each senior student is also required to do a design project and carry it through final assembly and testing. The development of the new laboratory has allowed us to establish valuable experimental set-ups for the existing courses as well as providing a vehicle for senior design projects in the areas of NN and FL. Students from various departments benefit from the educational principles provided by the laboratory instruction.

IV. Project Development

The project is intended to substantially improve the capability of undergraduate instruction related to recent developments in intelligent control technology. The proposed laboratory is aimed to supplement an introductory intelligent system course as well as four other courses. The contents of the lecture course address recent developments in intelligent system techniques using NN and FL control. Various applications such as temperature control, inverse pendulum, servo system, automatic focusing, and X-Y tracking systems are discussed in this course. The developed laboratory experiments are synchronized with the lectures. Students design the parameters of a NN or FL controllers for each real-time experiment in the laboratory and compare the system performance to proposed design techniques. The effect of design performance such as activation functions, number of selected layers for NN controllers as well as number of rules, fuzzifiers, defuzzifiers, selection of membership functions are investigated.

The development of the experiments for the laboratory is a natural outgrowth of several projects from an introductory course which has been offered during the last two years at FAU. The implementation and preliminary experimentation of Fuzzy Logic Controller (FLC) for DC servo, NN classification of electronic components, as well as X-Y table control movements have been previously carried out by the author using available equipment in Motorola Inc. Boynton Beach facility.

The developed laboratory addresses various designs and implementation issues related to NN and FL using six experimental stations. Each station consists of a personal computer, with A/D, D/A, Frame Grabber interfaces, and six different experimental facilities. Each station permits a number of different experiments to be performed. In real-time operation, the microcomputer sample experimental analog signals at variable rate through the A/D converter. Between samples the data pass through a fuzzification which convert it to linguistic terms. A rule based inference engine algorithm is generated to provide the desired fuzzy controller. The resulted linguistic values are converted to numerical numbers through defuzzification. The D/A converter provides the output of the system. One of the interesting features of the controller is the reduction in the number of rules and proper selection of membership functions. In addition, measurements can be taken directly by computer as the process operates and stored in the memory for the modeling and identification of the process using various NN algorithms. The resulted NN architecture can be utilized as a direct controller for the physical process in a closed-loop control strategy.

V. Experiments

The descriptions of some of the experiments are provided here. At least, three hours are required for the completion of most of the experimental set up.

(1): Controller design using Simulink, NN and FL Toolboxes
In this experiment Simulink, FL and NN Matlab toolboxes are used in order to familiarize the student with the simulated response of linear and nonlinear systems with FL and NN as controllers in the closed loop feedback configuration. The user-friendly environment of Matlab is also utilized profitably to obtain the proper NN and FL controllers of the real-time experiments.

(2): Dynamics of a Heat Process Trainer using NN
In this experiment, students are exposed to the concept of modeling a dynamic process using NN. The student selects a proper NN structure in terms of fidelity of the model with respect to physical process. A back-propagation NN is trained to learn the dynamic model of a Heat Trainer (PT 326). The dynamic of the processor is highly nonlinear with the airflow valve open more than 15 degrees. In the first phase of this experiment, the input-output data of the process is stored in the computer. In the second phase, various NN configurations are implemented by the student in order to obtain the non-linear mapping between input and output data.

(3): Performance Heat Trainer using a NN Controller
In this experiment, the NN mapping of the inverse dynamic model of the heat trainer are utilized as a direct controller for the provided process. The student selects a proper NN structure for controller design based on previous experiment. The selected NN controller is compared with a PID controller. Direct output comparisons are made with respect to set-point changes, effect of load disturbances and sensors relocations.

(4): Fuzzification, Defuzzification and Membership Functions
In this experiment, the student learns about fuzzification and defuzzification as well as inference rules of FLC. Students write a simple program with several fuzzy rules according to a look up table with given membership functions. The outputs of the fuzzy controller are displayed on the oscilloscope or plotted on a x-y plotter.

(5): Servo System Controller Design using Fuzzy Logic
In this experiment, the student designs a position and velocity feedback fuzzy controller for a servo system. The student writes the fuzzy inference rules based on a look-up table from the simulation results of the first experiment. Several fuzzy rules are eliminated in order to observe the robustness of the fuzzy controller.

(6): Invented Pendulum
This process provides an excellent application of fuzzy control. The student designs the fuzzy inference rule in advance. The performance of the fuzzy controller is tested in order to balance the pendulum . By changing the rod, the implementation of the fuzzy controller with different membership functions are carried out. The robustness of the controller are tested for various loads.

(7): Pattern Recognition and Motion Control of X-Y table using NN and FLC
This is one of the more advanced experiments for the laboratory. In the first phase of the experiment, students learn about NN classification. Students are provided with several patterns. The NN are trained using relevant discrete data information related to such patterns using stored data by the camera and frame grabber. In the second phase a new pattern is presented to the camera. The trained NN architecture predicts the presented pattern. In the second part of this experiment, a fuzzy logic controller is designed to move the X-Y table to a particular location. The student can place an object in the workspace of the system. The x-y table can be moved to different locations in order to find the object with the relevant data related to position and orientation of the object.

(8): Fuzzy Controller Design using an GP-6 Analog Computer as a Linear Plant
In this experiment, a GP-6 Analog Computer is utilized as a physical process with a selected transfer function. The digital computer is used for the implementation of a FL controller ` in a closed loop action. This experiment demonstrates the simulation concept of modeling as well as intelligent controller design and implementation in real-time for FL applications.

(9): Intelligent Control of a Reverse Osmosis Plant
This is also one of the more advance experiment of the laboratory. In this experiment the student will learn about the prediction as well as control of a small Reserve Osmosis Plant using Intelligent Control algorithms. A Neural Network will be trained available data from the plant's operation. The train NN architecture will predict the water quality similar to the algorithm as proposed in the experiment #7 of the laboratory. In the second phase of this experiment, a fuzzy logic controller will be designed in order to control the quality of the water parameters. In addition, the students will investigate plant behavior under different conditions, which may

cause problems to the normal operation of the unit. Several control parameters will be deliberately obstructed and changed from desired values. The effects of such variations and disturbances will be observed related to the system behavior in order to evaluate the robustness of the fuzzy controller.

VI. CONCLUSIONS

During the last few years, the need for new and innovative laboratory experiments in the area of soft computing is emerging. The implementation of the described intelligent Control laboratory at Florida Atlantic university should serve as a model for further development of these types of laboratory experiments within the spectrum of engineering discipline around the nation. The implementations of the various experiments have been successfully completed. The undergraduate students from EE and CSE will take the laboratory for the first time as an integrated part of an introductory intelligent system course during the spring 2001 semester.

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BIOGRAPHYY OF THE AUTHOR

ALI ZILOUCHIAN is currently the director of Intelligent Control laboratory and a professor in the Department of Electrical Engineering at Florida Atlantic University, Boca Raton, Florida. His most recent works involve the applications of soft computing methodologies to industrial processes including oil refineries, desalination processes, fuzzy control of jet engines, fuzzy controllers for car engines, kinematics and dynamic of serial and parallel robot manipulators. Dr. Zilouchian's research interests include the industrial applications of intelligent controls using Neural Network(NN), Fuzzy Logic (FL) and Genetic Algorithms (GA), Data Clustering, multidimensional signal processing, digital filtering and model reduction of large scale Systems. His recent projects has been funded by National Science Foundation and Motorola Inc. Feedback Inc., KISR and several other sources.

Dr. Zilouchian has taught more than 22 different courses in the areas of intelligent systems, controls, robotics, computer vision, and digital signal processing and electronic circuits at Florida Atlantic University and George Washington University. He has supervised 13 Ph.D., MS students and over 60 senior projects to completion during the last 14 years. In addition, he has served as a committee member in more than 25 MS theses and Ph.D. Dissertations. He has published over hundred (100) book chapters, textbook, scholarly journal papers and refereed conference proceedings. In 1996, Dr. Zilouchian was honored by a prestigious Florida Atlantic University Award for Excellence in Undergraduate Teaching.

Dr. Zilouchian is a senior member of IEEE, member of sigma Xi and New York Academy of Science and Tau Beta Pi. He received the outstanding leadership award for IEEE Branch Membership Development Activities for Region III in 1988. He has served as an NSF panel reviewer member, a session chair and an organizer of nine different sessions in the International conferences within the last five years. Currently, Dr. Zilouchian is *an Associate Editor* of the International Journal of Electrical and Computer Engineering out of Oxford, UK.