AC 2011-381: REAL-TIME CONTROL IMPLEMENTATION OF SIMPLE MECHATRONIC DEVICES USING MATLAB/SIMULINK/RTW PLATFORM

Abhijit Nagchaudhuri, University of Maryland, Eastern Shore

Abhijit Nagchaudhuri is a Professor in the Department of Engineering and Aviation Sciences at University of Maryland Eastern Shore. Dr. Nagchaudhuri is a member of ASME and ASEE professional societies and is actively involved in teaching and research in the fields of engineering mechanics, robotics, systems and control, design of mechanical and mechatronic systems, precision agriculture and remote sensing. Dr. Nagchaudhuri received his bachelors degree from Jadavpur University in Calcutta, India with a honors in Mechanical Engineering in 1983, thereafter, he worked in a multinational industry for 4 years before joining Tulane University as a graduate student in the fall of 1987. He received his M.S. degree from Tulane University in 1989 and Ph.D. degree from Duke University in 1992.

Real-time Control Implementation of Simple Mechatronic Devices Using MATLAB/Simulink/RTW Platform

Abstract

In this paper digital control solutions for speed control of direct current (DC) motor and level control of dual water tank system are described using conventional control algorithms such as (PID (Proportional + Integral + Derivative) and PI (Proportional + Integral)), as well as intelligent control algorithms based on fuzzy logic. The control algorithms are developed in the Simulink graphical programming environment. Using Real-time Workshop (RTW) build tools an optimized "C" language code is generated and compiled for real-time execution on the devices using a Visual C/C++ compiler, seamlessly. Appropriate software tools have also been utilized to allow remote activation of the systems. This capability allows realistic CAD (Computer Aided Design) drawings that accurately represent the physical systems on the remote terminals to exhibit appropriate motion corresponding to the actual movement of the physical system in the laboratory. The set-up is used for experiential learning and research efforts involving engineering and computer science majors at the university, as well as for demonstration purposes for the introductory Control Systems (ENGE 382) and Instrumentation (ENGE 380) courses offered by the author for engineering majors.

1.0 INTRODUCTION

Mechatronics[1-3] embodies the synergy of mechanical design, electronics, control, soft-computing and information technology.

In this paper various aspects of the field of "Mechatronics" is explored using simple laboratory devices – (a) Direct Current (DC) servo-motor and, (b) Dual water tank system, with appropriate electronic interfaces for sensing and control. Particular emphasis is paid towards (i) digital control using both conventional and intelligent control algorithms for speed control of the DC servo-motor and level-control of dual water tank system, and (ii) remote activation and observation of these devices over the internet. These devices have been installed in the University of Maryland Eastern Shore Mechatronics and Automation Laboratory(UMESMAL). Other equipment in the laboratory includes LEGO Mindstorms Robotics Invention System/NXT, CONTROL LAB from LEGO-DACTA, MIT HandyBoard and Handy Cricket for outreach activities to middle and high school students and/or freshman design projects; a four degree of freedom industrial SCARA robot, a computer vision system that can work with the SCARA robot for flexible automation tasks, as well as independent inspection and other applied image analysis tasks; digital control platforms for demonstration of vibration and control, inverted pendulum, and dual water tank system; various Computer Aided Engineering (CAE) software tools including, ProEngineer, Working Model 2D, basic MATLAB and associated toolboxes for

Statistics, Image Analysis, Neural Networks and Fuzzy Logic. Interested readers are encouraged to peruse reference[4] for an elaborate description of the laboratory.

2. REAL-TIME CONTROL PLATFORMS

Photograph [1] and Photograph [2] show digital servo-motor based platforms installed in the laboratory being utilized for control experiments for a compliant rotary link to demonstrate active damping, and a rotary inverted pendulum system to demonstrate control application to stabilize an open-loop unstable system. The DC servo-motor which forms the base of these devices is used to demonstrate the speed control experiments reported in this paper.
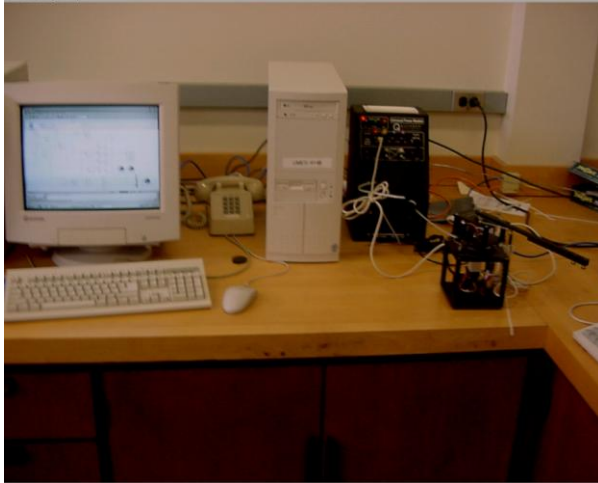
Photograph 1:Vibration Control Platform
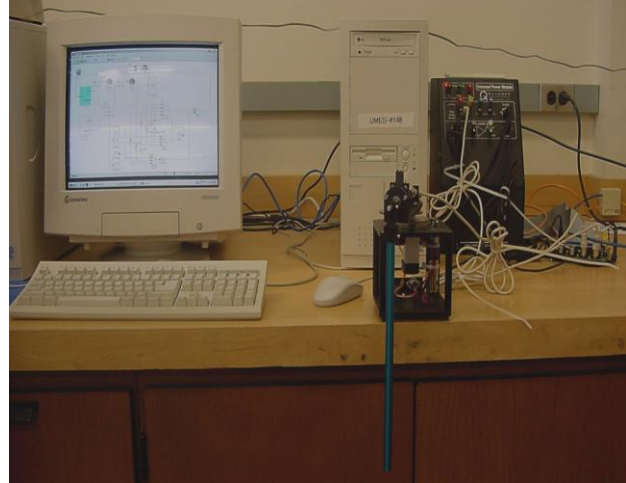
Photograph 2 : Rotary Inverted Pendulum.

Photograph 3. Dual Water Tank System

Photograph [3] shows the "Dual Water Tank" system. The system consists of two small water-tanks one on top of the other and a water reservoir at the bottom of the lower tank. Each tank has an outlet valve which can be opened or closed to various orifice diameters. Water flows from the top tank into the bottom tank. Both tanks have calibration marks on them for visual determination of the water level in the tanks. Each tank is also provided with a pressure sensor at the base which can be appropriately calibrated to determine the level of the water in each tank for feedback control purposes. The input to the system is via a water pump which feeds water to the top tank. The flow rate is controlled by speed of a direct current motor that drives the pump using input from a digital computer running an appropriate feedback control algorithm for various water level control tasks.

3. REAL-TIME CONTROL SOFTWARE TOOLS

The control algorithms are developed in Simulink, - a visual programming environment provided by Mathworks, which are interpreted and compiled via Real Time Windows Target, Real Time Workshop and a Visual C++ compiler. Digital control solutions involving (i) PI (Proportional + Integral) and PID (Proportional + Integral + Derivative) for control tasks such as keeping the water in the upper water tank at a constant level or varying water level in the upper water tank using a square wave or sinusoidal wave around a set level, (ii) optimal control of active vibration damping of the compliant joint system, and (iii) stabilizing a rotary pendulum vertically using optimal feedback using proportional and derivative gains have been implemented. Feedback gains have been adjusted to achieve desired response for all cases. These efforts and student demonstrations have been performed with the hardware set-up and basic framework of the Simulink code provided by Quanser Consulting Co: (QCC), the equipment vendor.

In this paper (i) PID and fuzzy control for speed control of a DC servomotor and (ii) PI and fuzzy control for water level control in the upper tank of the dual water tank system developed on the QCC platforms are elaborated. The demonstration of fuzzy control solutions developed in-house, and the remote activation capability, to undergraduate students in courses related to instrumentation and control provide an enriching exposure to promote interest in the high tech field.

4. PID AND FUZZY CONTROL OF DC MOTOR

Figure 1 shows the Simulink code for the PID control algorithm implemented to realize the speed control of a DC Servo-motor.
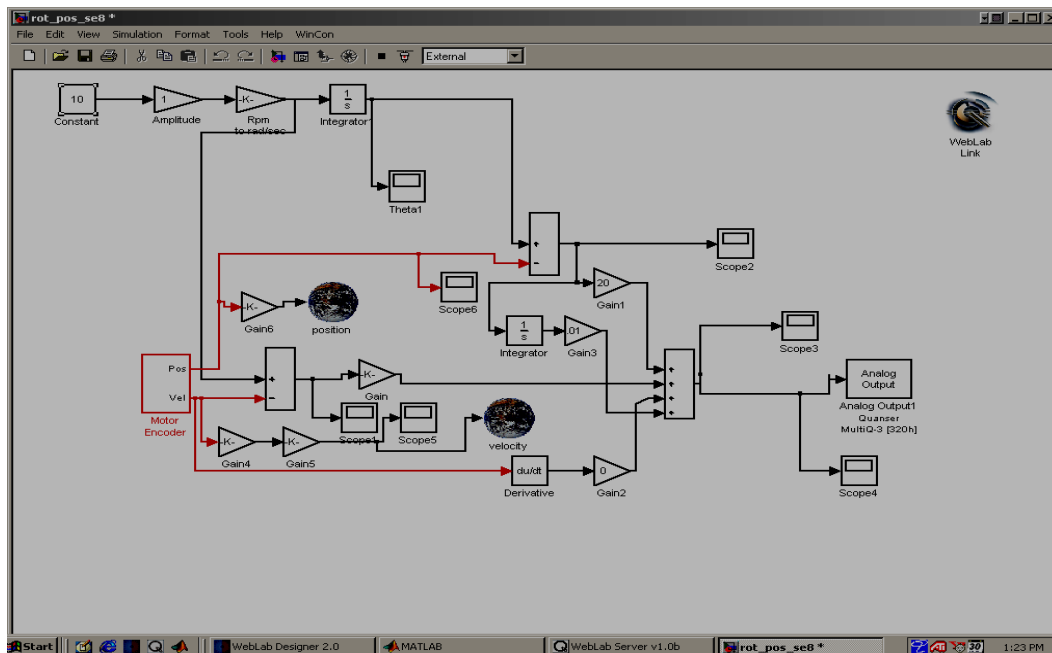

Fig. 1. Simulink code for PID control of DC motor

Simulink is an excellent visual/graphical programming tool for control algorithm development. It can use constant blocks, software comparators, gain blocks, scopes, pre-defined mathematical operations block, and variety of other pre-defined blocks on simulated or real-time signals to

generate appropriate control outputs to software displays, or to real hardware subsequent to digital to analog conversion.

In Figure 1, the desired speed (RPM) is inputted into the constant block shown in the upper left hand corner. The two gain blocks that follow are for (i) changing the desired speed by multiplying by an appropriate factor and (ii) to convert the desired speed from R.P.M to radians/sec. The block that follows performs integration of the signal to generate the position information in radians. This signal is sent to a comparator block as well as tapped off to a scope for display. The second input to the comparator block comes from the optical encoder attached to the motor. The signal from the encoder is high pass filtered appropriately to generate the actual velocity signal. With the desired and actual position and velocity signals it is possible to generate the appropriate error signals to produce the analog output signal corresponding to the voltage or current using PI, PD or PID algorithms. These signals then may be applied to the DC motor following digital to analog conversion.
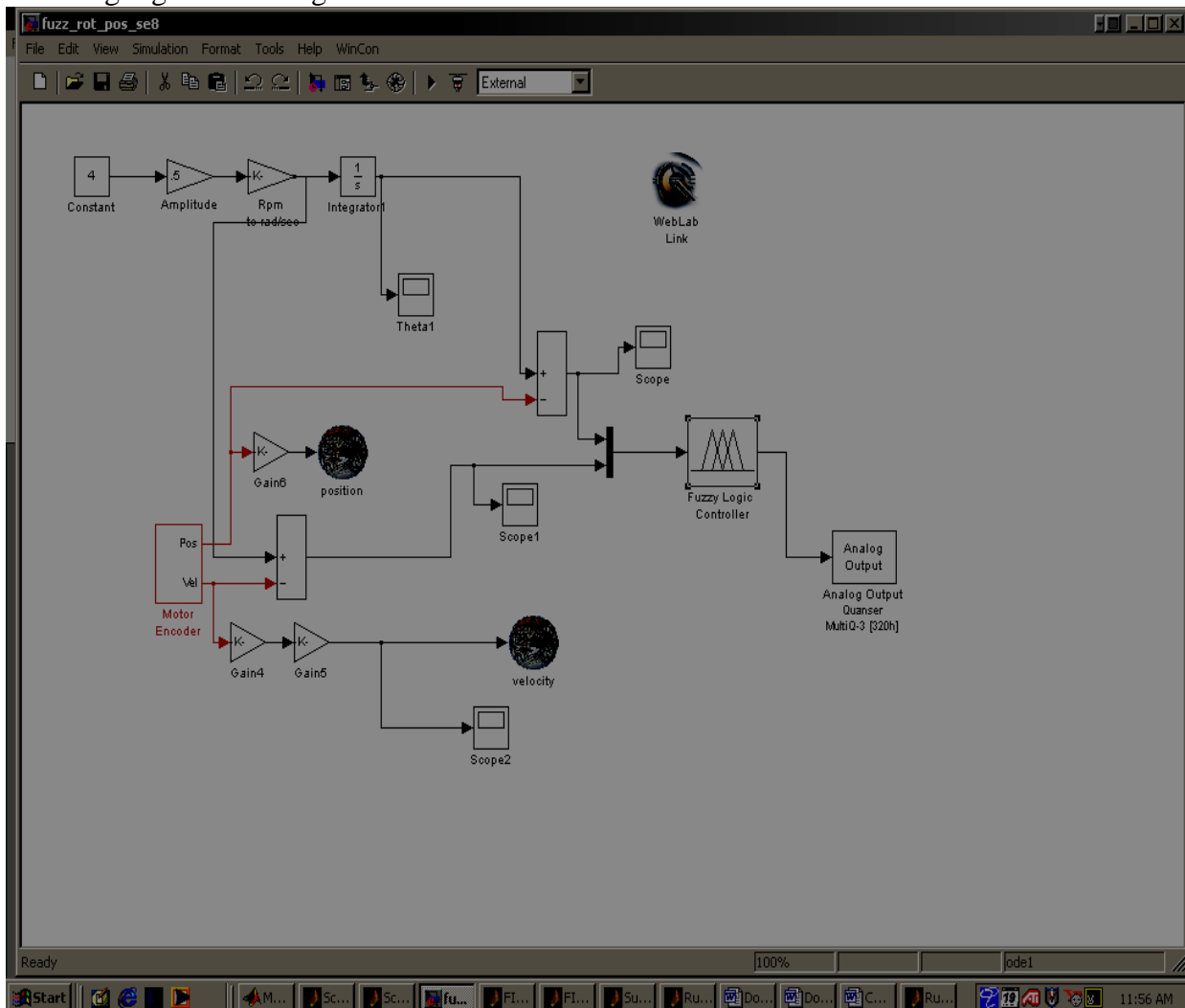

Fig. 2. Simulink code for fuzzy control of DC motor

In Figure 2 the position and velocity errors are obtained in a similar fashion and fed to a "Fuzzy Logic Controller(FLC)" block as shown.

TABLE 1: Fuzzy Tuning Rules

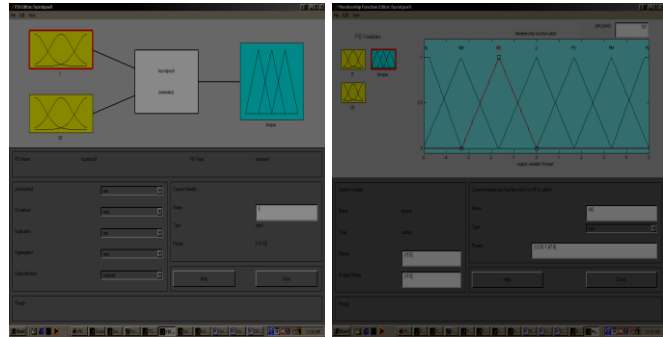| E/CE	N	Z	P
N	PM	PS	Z
Z	PS	Z	NS
P	Z	NS	NM

Fig. 3. & Fig. 4. (i) Fuzzy Inference System and (ii) Output Membership functions.

Table 1 provides the fuzzy tuning rules for the Mamdani type direct fuzzy controller used for the speed control of the DC servo-motor.

Figures [3] and [4] give a schematic overview of the Mamdani type fuzzy controller[5,6] developed using MATLAB's Fuzzy Logic Toolbox(FLT) for the servo-motor speed control. The FLT provides five graphical user interfaces (GUI) tools for building, editing, and observing fuzzy inference systems(FIS): (i)FIS editor (Fig 3),(ii) the Membership Function Editor that is used for both the input space and output space (Fig 4), (iii) the Rule Editor(Fig 5), (iv) the Surface Viewer(Fig 6) and (vii) the Rule Viewer (Fig 7).   The figures show the two fuzzified input membership functions representing the error and change in error, the fuzzy inference engine, and the fuzzy output membership function corresponding to actuator signal or motor torque. The error and change in error has been fuzzified into three overlapping levels N-negative, Z- zero and P-Positive. The output has more granularity and has seven levels but the two extremities are never reached. The nine rules as indicated in Figure 5 corresponding to Table 1 perform adequately. Figure 6 represents the mapping between the inputs (error and change in error) and the output torque using the fuzzy inference engine (rules).
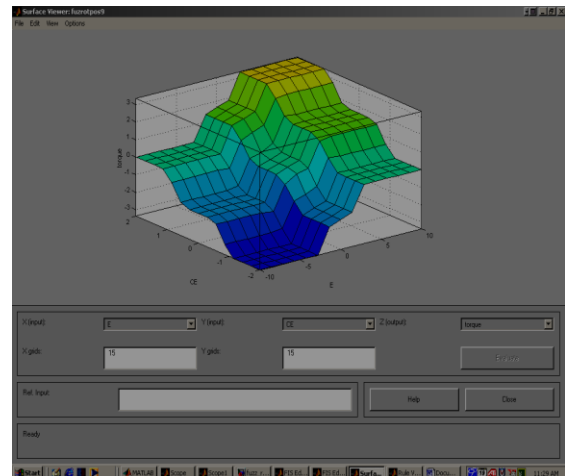

Fig. 5. & Fig. 6. (i) Fuzzy Rules and (ii) Fuzzy Input Output Map

Figure [7] shows an instance of fuzzy inference process, the inputs at the instant are such that two of the nine rules fire. The fuzzified outputs using the minimum rule of inference corresponding to 'and' are aggregated and defuzzified using the centroidal rule indicated by the vertical line drawn at the centroid of the area corresponding to the aggregate output. The FLC block shown in Figure 2 generates this output which is then transformed into an analog signal using a D/A converter before applying to the physical system using appropriate cabling.
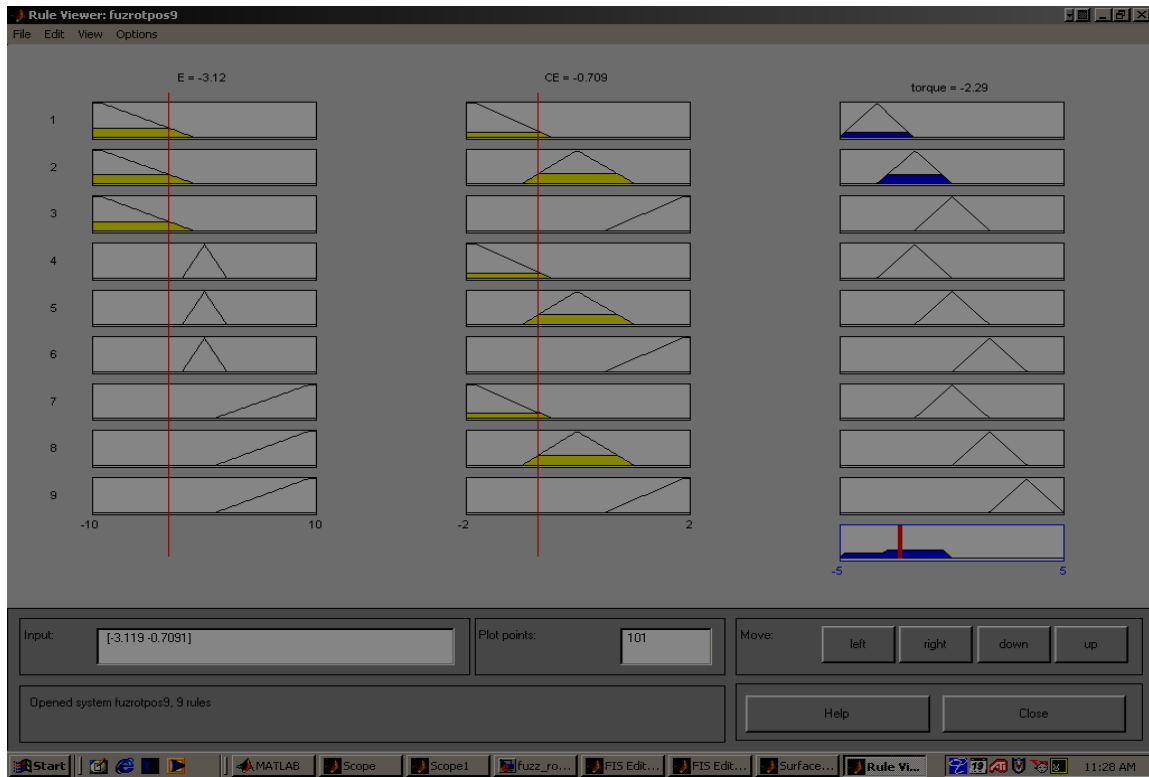

Fig. 7. Fuzzy Rule Viewer and Defuzzification

4. PI AND FUZZY CONTROL OF DUAL WATER TANK SYSTEM.

Figure [8] is a screenshot of Simulink code of PI (Proportional + Integral) control implemented for the level control of Dual-Water tank system. The desired level of water in the upper tank is set by the user using a Simulink constant block. As a variation the desired level can be superimposed with a square, sinusoidal or other suitably shaped pulse with a small amplitude and frequency so as to require the water level to vary around a set point according to the shape of the pulse. This can be conveniently achieved using pre-defined blocks in Simulink. The error in level is computed using a comparator block which finds the difference between actual level measured with a pressure sensor and the desired level set by the user. The error signal is used in conjunction with appropriately tuned proportional and integral gains to achieve the level control by varying the speed of a DC motor connected to a water pump. The raw reading of the level sensor is very noisy due to bubbles, inflow of water from the pump etc. and is appropriately filtered using a suitable low-pass filter block in Simulink. A basic conventional controller designed in the Simulink environment was supplied by the vendor (Quanser Consulting Co:; http://www.quanser.com).
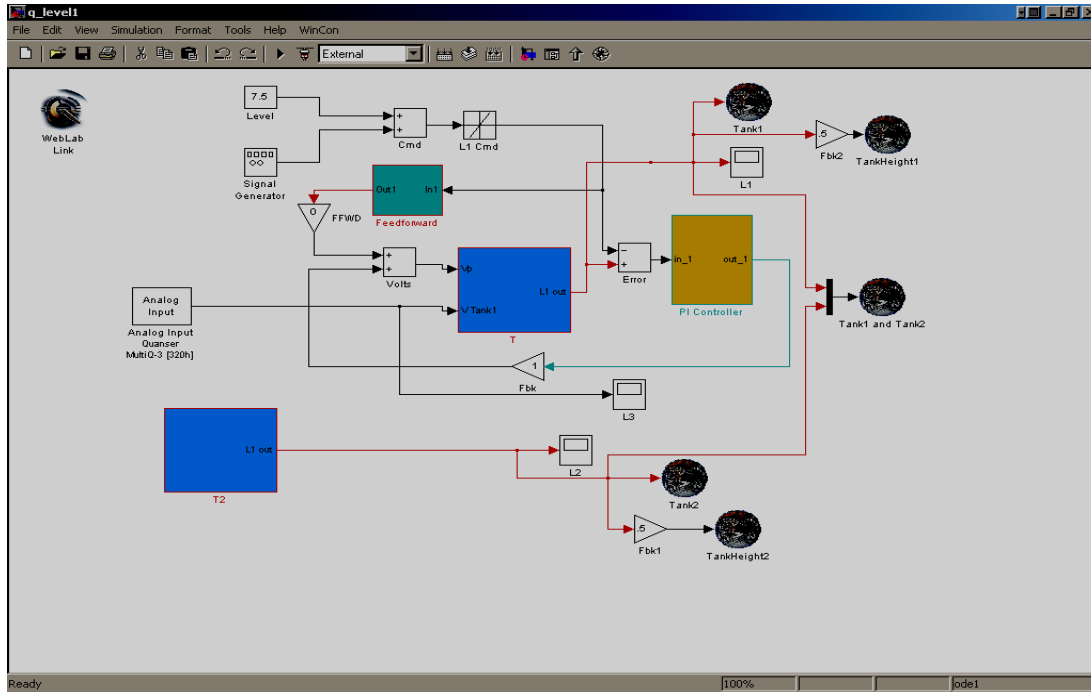
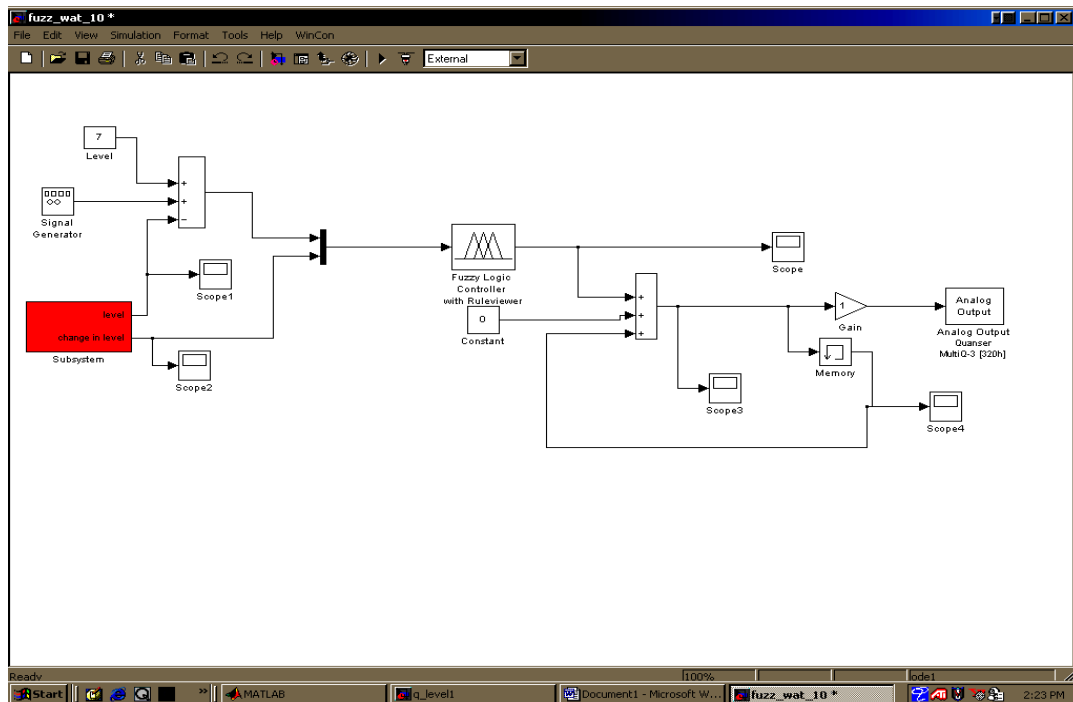Fig. 8. Simulink code for PI control of Dual Water Tank system

Fig 9. Simulink code for fuzzy control of Dual Water Tank system.

Figure [9] is the Simulink code developed by the author for performing the same level control task described before using the PI controller with fuzzy logic. As in the PI controller the user sets the desired level using a constant block and the error is computed by comparing the actual

level measured by the level sensor. Level error and change in error level is fuzzified using three overlapping membership functions similar to the fuzzification described for the DC motor fuzzy control.

Table 2. FIS rules for Dual water tank system

1. If (level is high) and (ch_in_lev is neg) then (output1 is cf) (1)
2. If (level is high) and (ch_in_lev is zer) then (output1 is cm) (1)
3. If (level is high) and (ch_in_lev is pos) then (output1 is cs) (1)
4. If (level is ok) and (ch_in_lev is neg) then (output1 is cs) (1)
5. If (level is ok) and (ch_in_lev is zer) then (output1 is nc) (1)
6. If (level is ok) and (ch_in_lev is pos) then (output1 is os) (1)
7. If (level is low) and (ch_in_lev is neg) then (output1 is os) (1)
8. If (level is low) and (ch_in_lev is zer) then (output1 is om) (1)
9. If (level is low) and (ch_in_lev is pos) then (output1 is of) (1)

The rules given in Table-2 are used as part of the Fuzzy Inference System (FIS) to generate the fuzzy output, where cf, cm and cs stand for closefast, closemedium and closeslow, nc stands for no change and os,om and of stand for openfast, openmedium and openslow. Intuitive rules correspond to how a user would operate a valve for a water tap to adjust the water level. The memory block in Simulink is used to feedback the water level from the previous level and fuzzy controller does the fine adjustments.
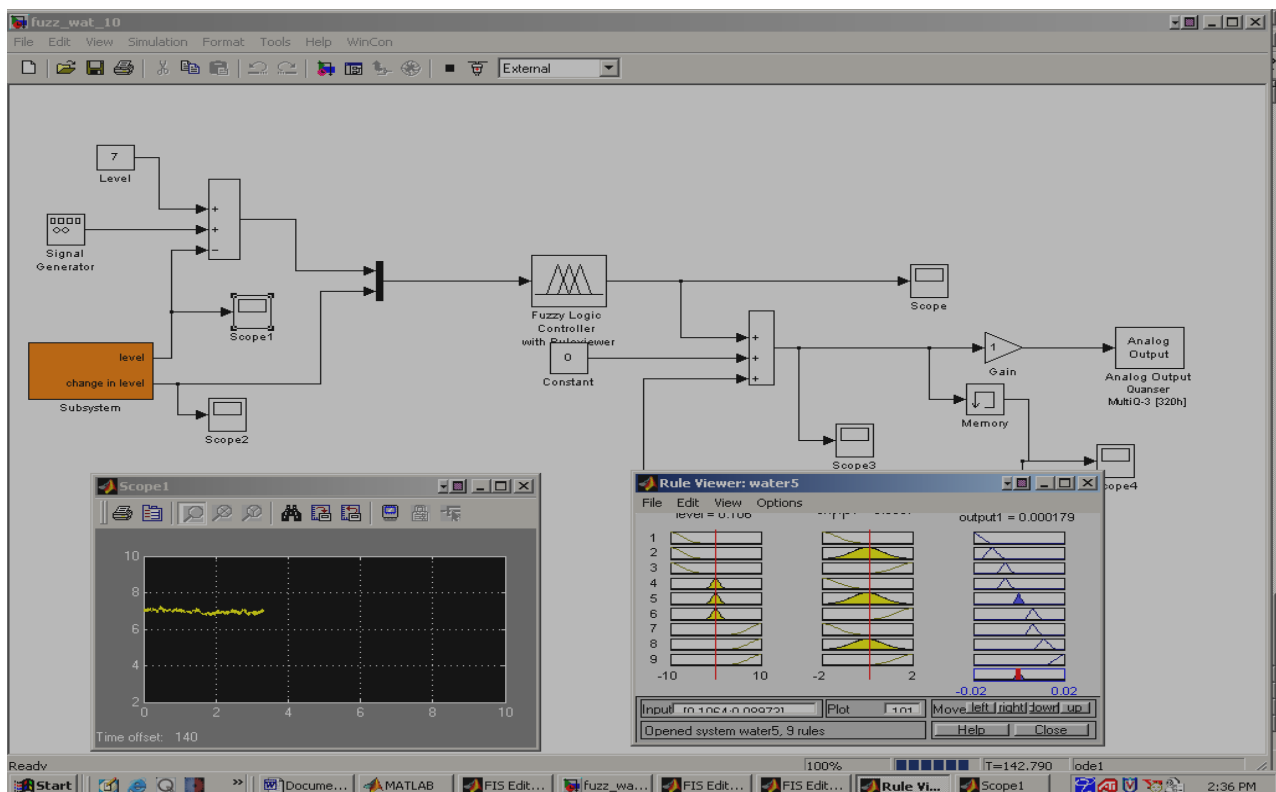

Fig. 10. Fuzzy Rule Viewer with Simulink code and output scope

Figure 10 is a screen shot captured during the real-time execution of the level control algorithm which shows the Simulink code, a software scope that indicates that the desired level has been achieve, and the fuzzy rule viewer.

5. REMOTE ACTIVATION AND OBERVATION USING WEBLAB.

Weblab, a software tool for controlling the systems described over the internet was used to activate, as well as observe the systems over the internet. The software was acquired from Quanser Consulting Company. The three main components of the software are Weblab Server , Weblab Bean and Weblab Designer. The Weblab server serves sensor and actuator data corresponding to the system to clients that have Weblab Designer installed on them. Weblab Bean provides the interface between Simulink and Weblab Designer for data transfer. Weblab Designer has a 2-dimensional, as well as a 3-dimensional computer aided design (CAD) tool integrated with it. The Weblab Designer allows development of an accurate graphical model of the system using the integrated CAD tool which can use the digitized sensor and actuator data from the physical system over the internet to provide a realistic kinematic picture of the actual system at the client end. The software allows the control gains to be set from the client end and observation of a realistic representation of the manifestation of the control action on the physical
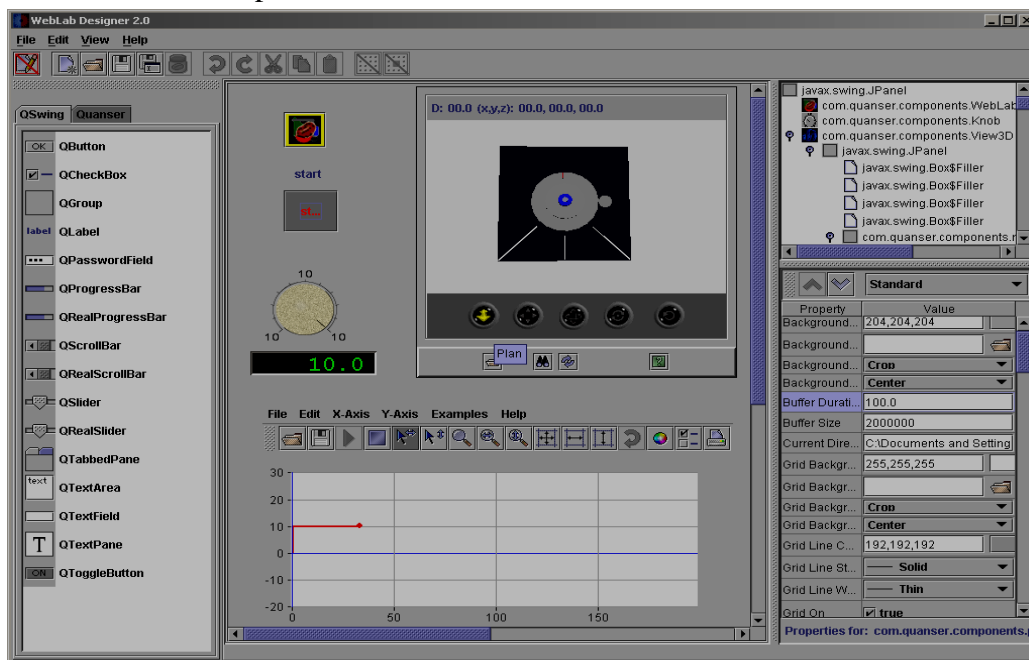

Fig. 11. Web display of DC Servo-motor control

device using actual data over the internet, remotely. Since the data is made available at the client, appropriate graphical plots can also be generated remotely. Figures [11] and [12] are screenshots of sample Simulink code and an instant of the graphical display of the tele-reality at the client end of the DC motor and the Dual water tank system.

6. CONCLUSION
In this paper preliminary results of intelligent control and remote activation of mechatronic devices that are being used for education and research at the University of Maryland Eastern

Shore Mechatronics and Automation Laboratory (UMESMAL) have been described. Other activities in the laboratory include robotics, machine vision, image processing, mechanical design, modeling and simulation, soft computing using neural networks, fuzzy logic and conventional statistical analysis.
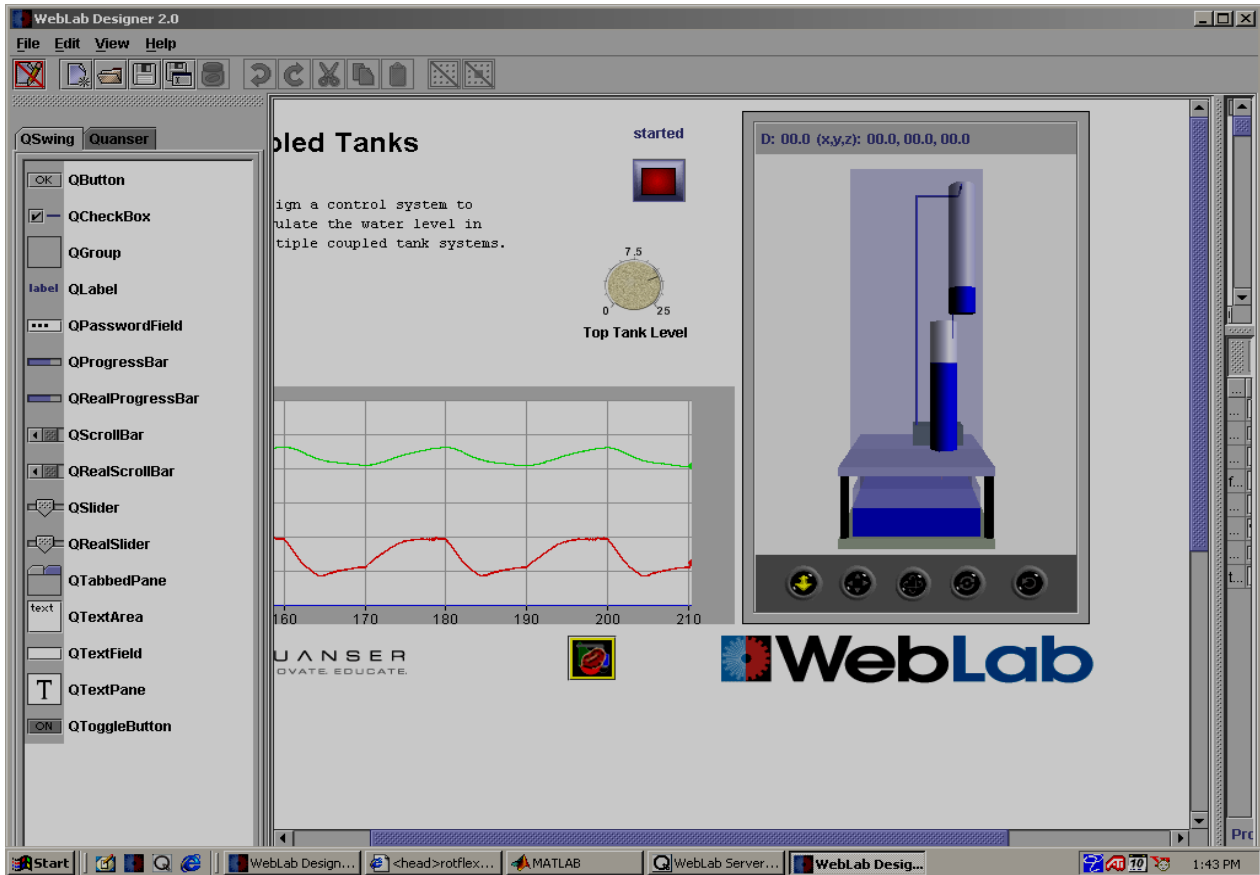

Fig. 12. Web display of Dual Water Tank control

The platforms described are used for experiential learning and research efforts involving engineering and computer science majors at the university, as well as for demonstration purposes for the introductory Control Systems (ENGE 382) and Instrumentation (ENGE 380) courses offered by the author for engineering majors. Both courses are offered as 3 credit lecture courses. During the laboratory demonstrations for the Instrumentation course (ENGE 380) the sensors such as the potentiometer and optical encoder that are integrated with the DC motor based platforms and the level sensor integrated with Dual Water Tank platform in the laboratory are highlighted. Students also observe how position signal from the optical encoder can be high pass filtered to obtain a velocity signal and how the level sensor is low pass filtered to eliminate sensor noise due to the bubbles in the level sensor. Students also get some hands on field of various sensors and data-loggers in the project assignment in the course. Logistics related to credit hour limitations, and number of units available prohibits students in the Control Systems (ENGE 382) course to get a comprehensive hands-on exposure to the hardware devices in the laboratory. Extensive MATLAB and Simulink based simulations are integrated with the project and homework assignments in the course for the students to appreciate the laboratory

demonstrations of control implementation on real-hardware, particularly for the classical control algorithms (PI, PD, PID etc). It is hoped that introduction to fuzzy logic and intelligent control algorithms, as well as, exposure to remote activation and tele-reality capability provides the motivation to the students for continued learning in this rapidly changing high-tech field consistent with the ABET outcome of life-long learning. Formal assessment of learning outcomes related to laboratory demonstrations have not been performed for the undergraduate students. Anecdotal evidence based on discussion with students indicate that the laboratory exposure not only helped them relate the theory to practice but also helped them comprehend the abstractions in course lectures from a physical framework they could relate to. The exposure has also provided motivation for some students for further studies in the area of control systems and mechatronics at the graduate level.

7. ACKNOWLEDGMENT

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