Project Deliverable III
Senior Project Proposal for

Non-Linear Internal Model Controller Design for a Robot Arm with Artificial Neural Networks

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Project Abstract

This project is centered around controlling the Quanser Consulting Plant SRV-02 with a Non Linear Internal Model Controller implemented with Artificial Neural Networks. The Quanser Plant consists of a stand supporting the base, an arm connected to the base with springs, and a base housing a DC motor driving the arm. The plant consists of 2 degrees of freedom originating at the motor in the base and the springs at the arm creating a 4th order plant. Artificial Neural Networks with an adaptive transfer characteristic coupled with accurate disturbance detection of Internal Model Controller can help us design a controller to manage the 4th order Quanser Plant despite its' non-linearities and external disturbances.

Introduction

This project deliverable will combine the description of the project developed in Project Deliverable I and II to provide a developed Senior Project Proposal. Preliminary computer simulations results, analytical evaluations, system identification results, considerations for extra equipment, schedule for semester 2 have also been added. In essence, this deliverable summarizes all research and work completed on the project in the Fall '07 semester.

Physical and Functional Description

The Quanser Consulting Plant SRV-02 consists of an arm, base, and stand. The stand contains a motor driving the arm through a gear train in the base. When electrical energy is supplied to the motor the result is mechanical energy, torque, at the output shaft. The gear train moves the arm and this creates the 1st degree of freedom(DOF). There are also springs attached from the arm to the base. This along with friction in the rotary flexible joint forces the arm to move independently creating a 2nd DOF(Dempsey,2007). DOF's add to the degree of the system plant, more on this in the functional description. The top down view of the system is shown in Figure 1 below. A side view of the system is shown in Figure 2 on the next page.

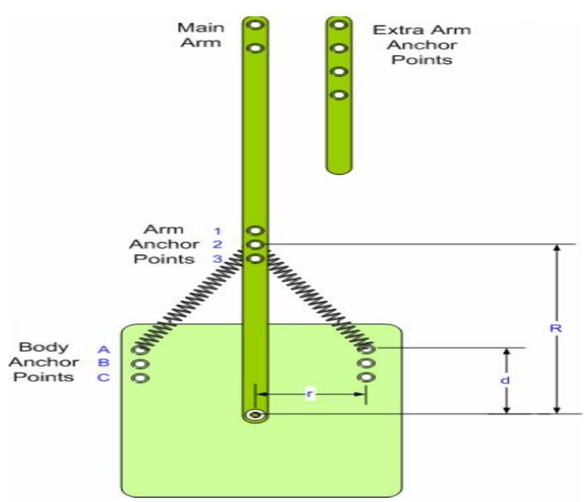

Figure 1 - Top-down view of the system showing the arm and base. Note the output shaft of the motor connected to the arm through a gear train in the center of the base(Edwards).

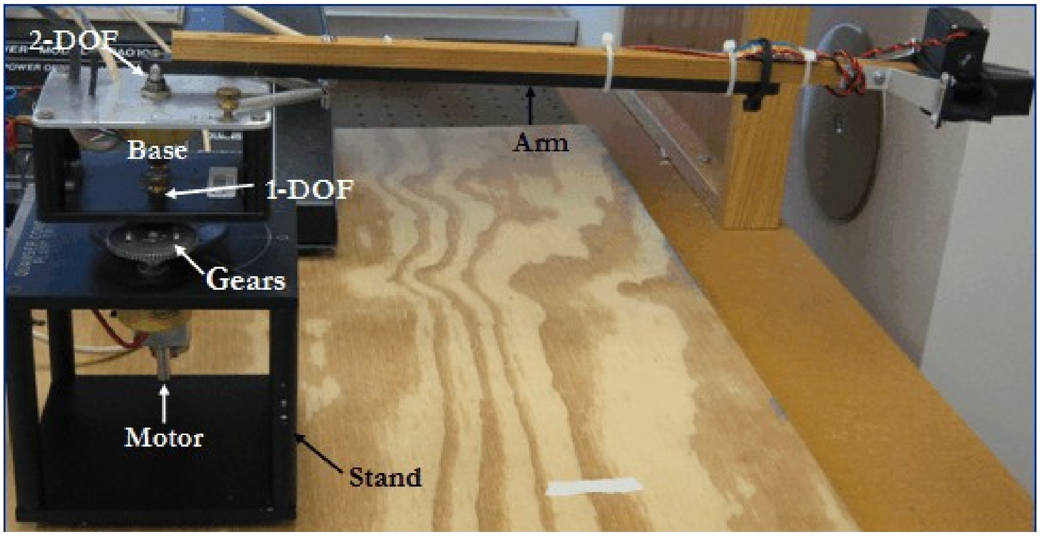

Figure 2 – Quanser Consulting System SRV-02 – Stand, base, arm and gears are shown. There are arrows pointing out where the DOFs originate (Dempsey, 2007)

The hardware shown above communicates with a 1.46Ghz Pentium-based computer with an internal A/D and D/A acquisition card. The system can be described using a low level system block diagram as shown in Figure 3 below. Lastly, the system is connected to a sophisticated power amplifier for driving the entire system shown as the amplifier in Figure 3 below.

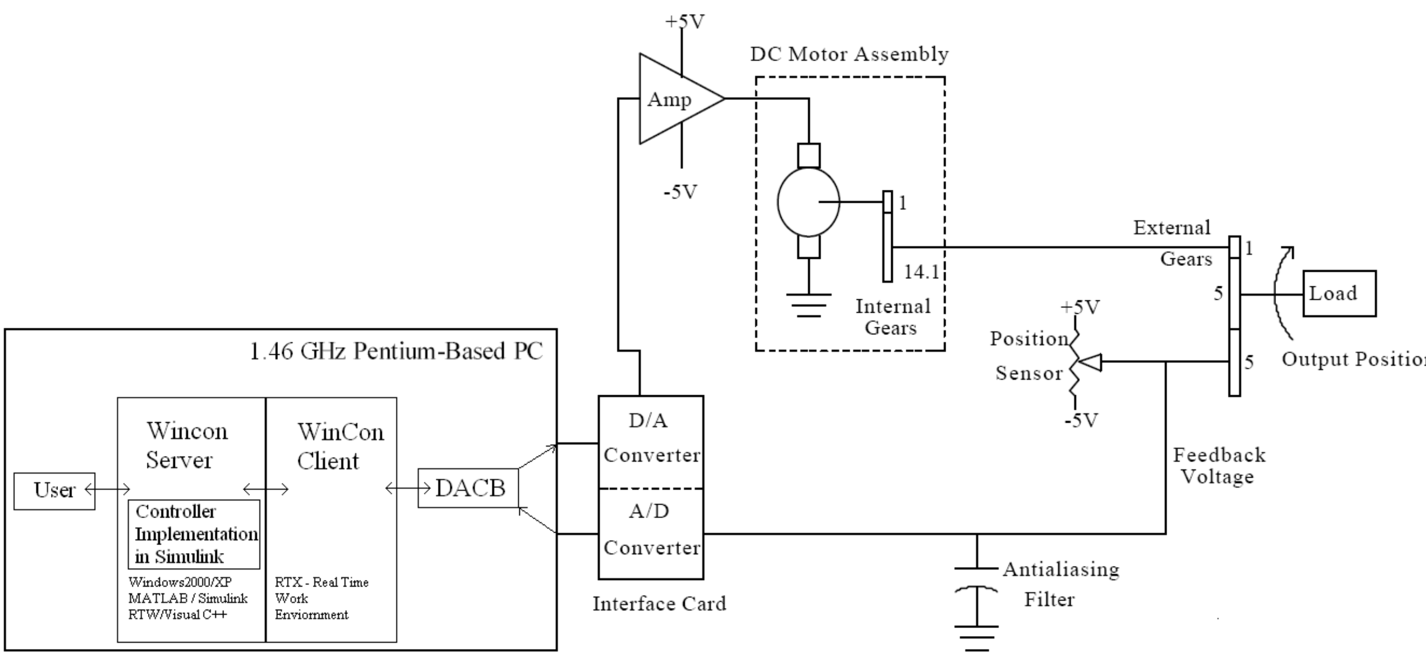

Figure 3 – High level block diagram. Note the DACB interface card housed in the PC, gears, feedback voltage loop and the anti-aliasing filter.

Software Interface

As shown in Figure 3, the PC contains a user interface for the Quanser Plant using WinCon and Simulink on a Windows based PC. WinCon enables you to create and control a real-time process entirely through Simulink and execute it entirely independent of Simulink. Diagnostics and position sensor output can be measured numerically, graphically, and is collected on the computer in real time. This is possible with the A/D and D/A converters on the Data Acquisition and Control Buffer(DACB) communicating with WinCon using the Real Time Execution(RTX) Workshop installed in Simulink. By implementing controllers in Simulink it is possible measure the real time response of the plant.

Functional Requirements and Performance Specifications

This project flow will be such that controller complexity will increase with every step in effort of achieving all performance specifications. These specifications will be the standard of comparison for each controller design. The list below shows these set of specifications.

- Percent Overshoot 5% max
- Time to Peak(max) 50ms max
- Time to settle 200ms max
- Closed Loop Bandwidth 2Hz min
- Peak Closed Loop Frequency Response 3dB max
- Gain Margin 5.0 min
- Phase Margin 60 degrees min
- Steady State Error 1 degree max
- Controller Execution Time 1ms max

The controller development flow, where each step can be considered a functional requirement is listed below.

1. Single Loop – Proportional , Proportional–Derivative Controller
2. Single Loop – Feed Forward
3. Feed Forwards with Artificial Neural Networks
4. Internal Model Control with Artificial Neural Networks

Research Significance

The research focus of this project will be minimizing the effects of external disturbances from the 2 degrees of freedom, from the rotary flexible joint, and picking up and dropping external loads with the gripper using the Quanser SRV-02 plant. From research, Internal Model Controller design is the best solution. However, the project cost of this approach compared with more conventional methods is not clear. Thus elements such as cost, performance, complexity, precision, accuracy, and design time will be explored in this project.

Internal Model Control and Artificial Neural Networks

After conventional system identification of Gp(s), the process or plant model, and several controller design iterations, stated in the Functional Requirements, Internal Model Controller(IMC) design will begin. Refer to Figure 4 below where Quanser plant is shown as Gp(s). The Internal Model

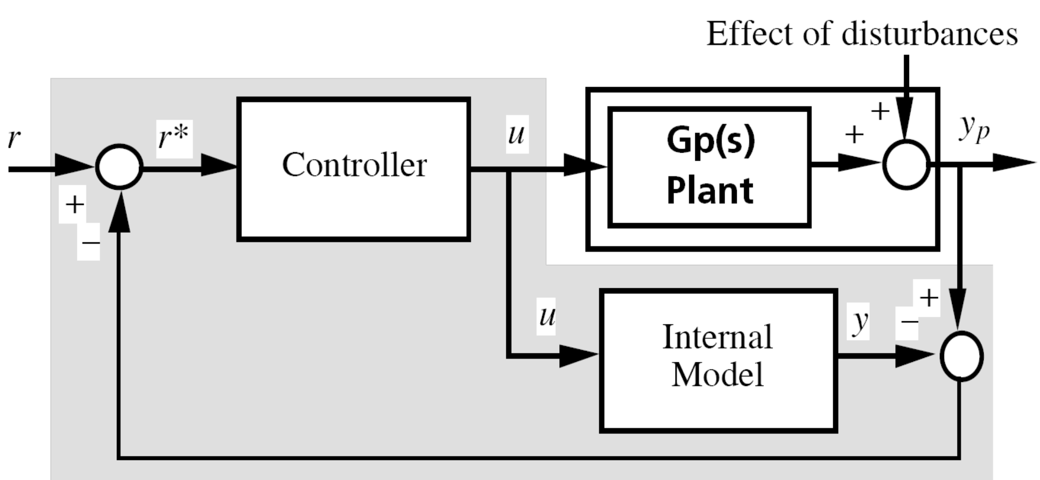

Figure 4 - Block Diagram for Internal Model Controller

Controller produces the difference between Gp(s) and the 'internal model' of Gp(s) providing the effects of the disturbances. The disturbance is then minimized by the controller. It is yet to be determined which type of controller will maximize IMC controller performance. Traditional internal models are simulated by linear system design technique. However, a fourth order model would be more accurate because non-linearities exist from gear backlash, static friction and coulomb friction. Thus, an internal model for non-linear systems needs to be simulated with Artificial Neural Networks(ANNs).

ANNs are adaptive systems that can change their input-output internal structure during the learning phase based on feedback. In practice, ANNs are used to model non-linear systems. The network consists of a number of inputs and a hidden layer of nodes connected to each input which process the data to generate an output. Each connection from an input to node has a variable numerical weight. In the learning phase, the output is fed back to 'tune' the numerical weights so they change to fit the proper I/O characteristics. For our case the ANNs would simulate the I/O characteristics of the Quanser Plant SRV-02. Figure 6 below shows the node structure of ANNs.

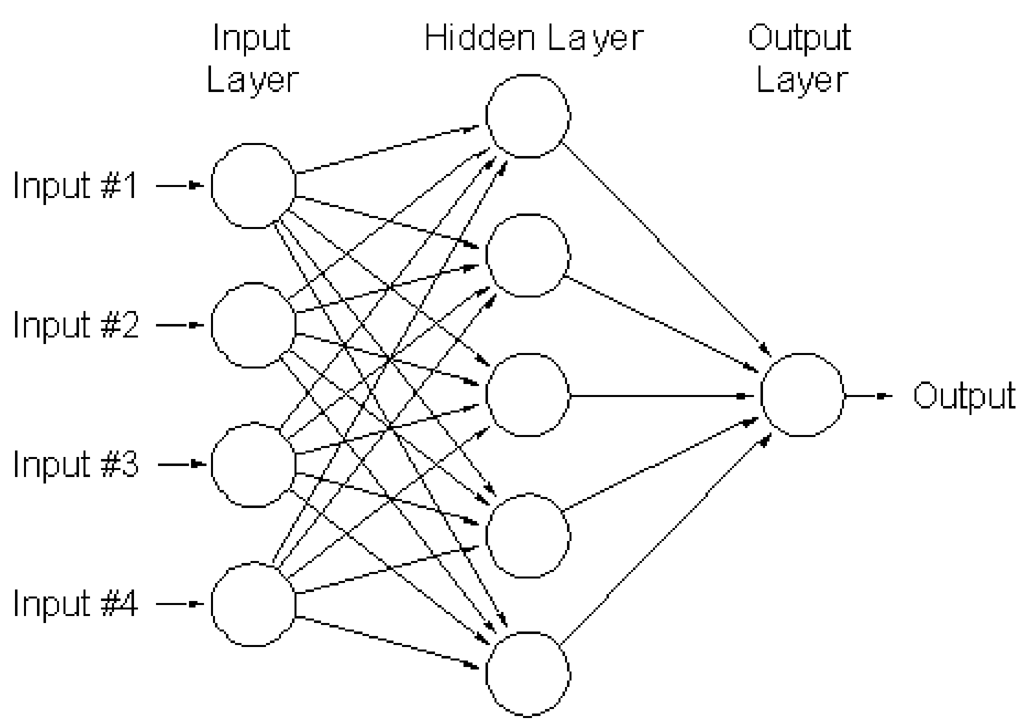

Figure 6 - Artificial Neural Network

System Identification

Currently, System Identification has been performed experimentally on the Quanser Plant without the arm. This essentially made the plant 2nd order with time delay. The plant gain, time delay, and pole locations were identified to be...

$$Gp(s) = \frac{69e^{-s(35ms)}}{s(s/50+1)}$$

The figure below shows a comparison of the step response for the identified plant and experimental results.

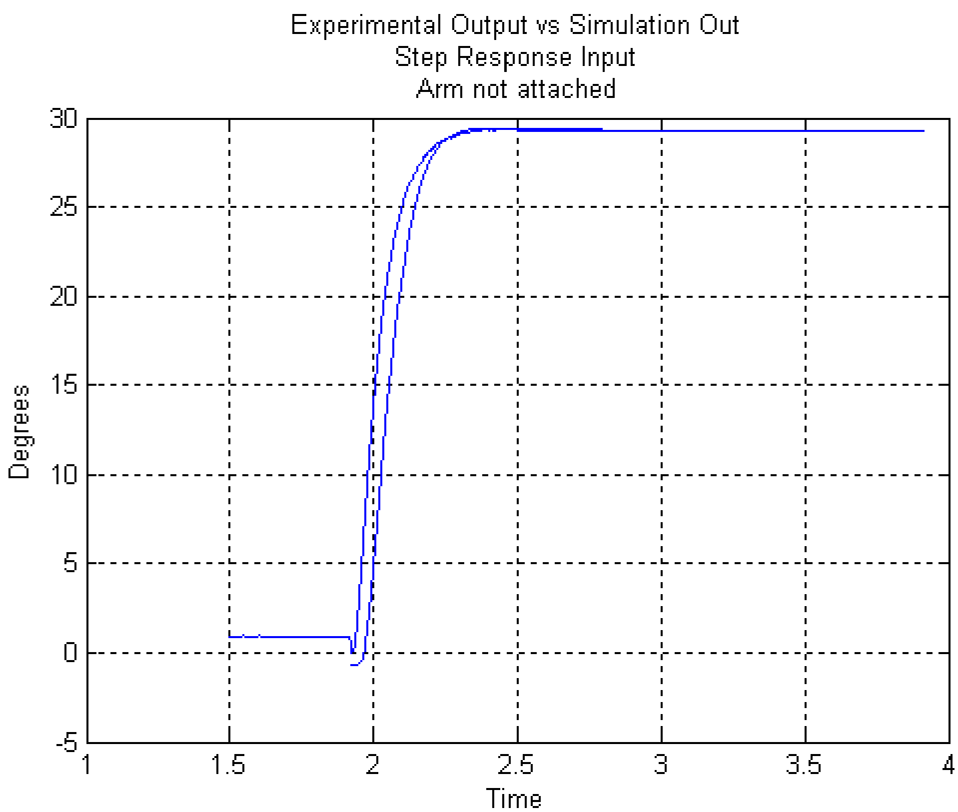

Figure 7 – System Identification Results vs. Experimental

P and PD controller design

Controller design without the arm on the plant has been performed. P and PD controllers were implemented.

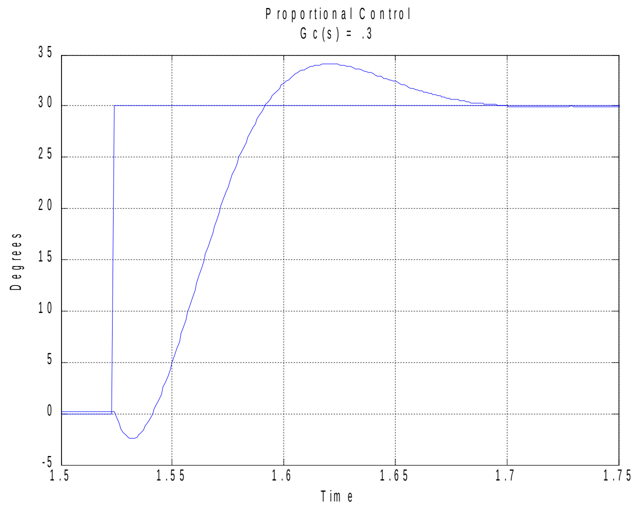

Figure 8 – Proportional controller results

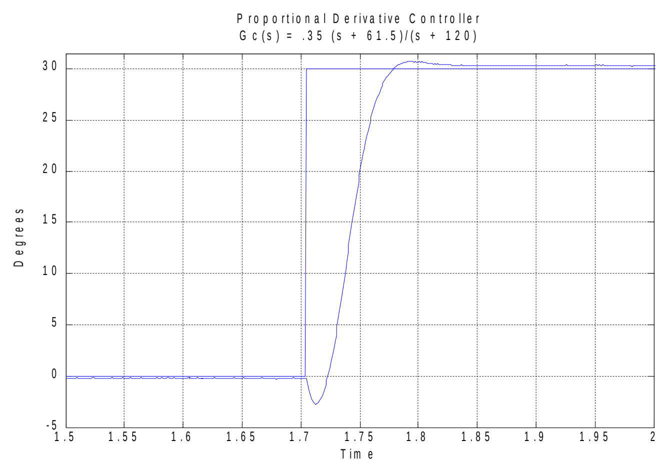

Figure 9 – Proportional Derivative controller results

The data for these two controllers is shown in Table 1 below. Note the increase in performance.

		PD Controller		P controller
	Experimental	Hand Calculations	Experimental	Hand Calculations
Gain	0.61	35.0067	0.303	17.4
Tp	0.09	0.036	0.1	0.084
Ts	0.1	0.06	0.16	0.13
% O.S.	4%	5%	16.20%	4.60%

Experimental K = Hand K * pi/180

Table 1 – P and PD controller results

Schedule

Week	Task
1	Single Loop Feed Forward Design
2	Internal Model Controller with approximate Linear Model
3	Train Adaline with Linear model
4	Implement Adaline in Internal Model Control
5-6	Train Adaline with plant in real time
7	Implement Adaline in Internal Model Controller
8	Performance testing, comparison with conventional methods
9-12	Left open for finalization, additional work, presentations and reports

Considerations for Extra Equipment: No further equipment is required.

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