Digital Controller Designs for Plants with a High-Degree of Friction

by

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Submitted to:

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Project Summary:

The goal for this senior project is to design and develop C code for a small robot arm assembly controller using an enhanced 8051 microcontroller (80535). Various controllers will be designed in an attempt to increase the speed and accuracy of the robot arm without excessive overshoot. Safety features such as motor current limit protection, and motor disable software for excessive position displacements will also be added. The add-on keypad and LCD (Liquid Crystal Display) will be used to provide a user-friendly interface for controller entry and status information. Evaluation of the C code implementation in regard to real-time execution, requirements for RAM and ROM, and development time will be important to future senior project development by Dr. Dempsey.

Narrative:

In the last ten years, the National Science Foundation's control theory directors and advisory committee members have encouraged exploration of new control methods for complex industry applications. This has been evident in NSF sponsored workshops and textbooks [1,2]. Artificial neural network, fuzzy logic, and neural-fuzzy controllers have been the emphasis and have received the most funding. Although these methods have been used for many non-control applications, they have not been applied widely in industry to nonlinear control applications. Also, these new methods have not been compared sufficiently to other classical adaptive and non-adaptive approaches.

The hydraulic systems area will be one of the more challenging areas for adaptive control especially in the large machinery area. The predominant method used in industry is human control. Many product parameters cannot even be specified because they rely on the person's experience and training. Automatic adaptive electronic controllers can eliminate the repetitive tasks performed by the human controllers as well as achieving better performance such as final position accuracy. Final positioning accuracy has only become a concern in the last several years. Good accuracy is difficult to obtain with conventional controllers. Autonomous (remote-controlled) vehicles used in mining and hazardous environments have been one area where control and product specifications are critical.

The first step to improve the hydraulic system is to add a conventional closed-loop electronic controller. The PID controller is the most widely used controller in industry and also the easiest method to design and implement. However, there are many problems and challenges with the PID controller for the large machinery hydraulic applications. The nonlinear time-varying parameters of the hydraulic system present a challenge for this control design method. Faculty research and a MSEE Thesis were recently completed regarding conventional PID controller design for a Caterpillar wheel loader, which is hydraulically controlled [3-6]. One product specification (speed) could not be met with the PID controller design. The primary limitation of the PID controller is that it is not adaptive to the different load conditions found in the large hydraulic system area. For example, the wheel loader's bucket load can vary from 0 to 33,000 pounds. An adaptive controller method can make the hydraulic system insensitive to varying load conditions. Experienced human operators can also perform this task but the electronic equivalent can provide better positioning accuracy and eliminate monotonous repetitive tasks from the operator.

In these hydraulic applications the cylinders can be several meters in length and are intended for efficient transmission of power and amplification of force. The cost of hydraulic systems used in large machinery can be on the order of hundreds of thousands of dollars. Control testing is normally performed on much smaller platforms such as robot arms, which can be designed to exhibit dynamics similar to larger hydraulic systems. Small robot arm systems can be purchased for approximately $6,000 for control algorithm testing. The robot arm system being used in our laboratory is very similar to the dynamics of the Caterpillar wheel loader. The mass, length, and type of robot arm were constructed by Dr. Dempsey to match the hydraulic dynamics. Five projects have been supervised with the robot arm systems provided by 1994 and 1999 Bradley Research Awards. Each robot arm assembly requires little laboratory space. The existing system requires a laboratory bench space of approximately six feet by two feet. The weight of the system is about twenty pounds.

The goal for this senior project is to design and develop C code for a small robot arm assembly controller using an enhanced 8051 microcontroller (80535). During the 1999/2000 school year, Megan Bern and Ritesh Patel designed and constructed an A/D and D/A converter interface board for the microcontroller board. This interface converts unipolar signals to bipolar signals for use in this system.

Various control systems will be utilized in an attempt to increase the speed and accuracy of the robot arm without excessive overshoot. Safety features such as motor current limit protection, and motor disable software for excessive position displacements will also be added. The add-on keypad and LCD (Liquid Crystal Display) will be used to provide a user-friendly interface for controller entry and status information. The user interface of the LCD shall consist of a menu from which the user may select either the command mode or the signal display mode. If the command mode is selected, options such as controller type, command position, command velocity, where the command signal is coming from, or a maximum position setting can be displayed and entered by the user. When signal display mode is selected, either the arm position, the command position, the error signal, or control signals may be displayed. These signals are defined in Figure 1. The inputs and outputs of the system are listed below.

<u>INPUTS:</u>

- A/D Channels
  - -Arm Position
  - -Joystick Position
  - -Motor Current
- Keypad

<u>OUTPUTS:</u>

- D/A Channels
  - -Controller Output
  - -Error Signal
  - -Command Signal
  - -Feed-forward Signal
  - -PID-type Controller Signal
  - -Filtered Position Signal
- Port Output – "Kill" Relay
- LCD Display

A high-level block diagram is shown in Figure 2. It includes the microcontroller development board, the DC motor assembly, some external gears, and a position sensor. The development board consists of a keypad, a LCD display, A/D and D/A converters, and the 80535 microcontroller. The microcontroller provides 24 bits of digital I/O, 4 counters/timers, and 10 external interrupts. The microcontroller board is manufactured by EMAC Inc., which is located in Carbondale, IL.

The D/A converter output drives the external power amplifier, which is connected in a voltage-follower configuration. The amplifier can supply a maximum of 3 Amps to a DC motor. The DC motor converts the control voltage to a mechanical position and velocity. The external gears provide a 70.5 reduction in rotor velocity for the external robot arm load. This arrangement is beneficial because the motor "sees" a small load; i.e., the gears step-up torque.

A potentiometer is used for the position sensor. The pot arm is connected to the robot arm via a 1:1 gear. A voltage supply of +/- 5 volts is used for the pot so that the arm position of zero degrees corresponds to zero volts. The power amplifier, DC motor, gear train, and potentiometer are part of a system manufactured by Quanser Consulting. The company also provides test software and simple controller software for their system.

Figure 1: Control System Block Diagram

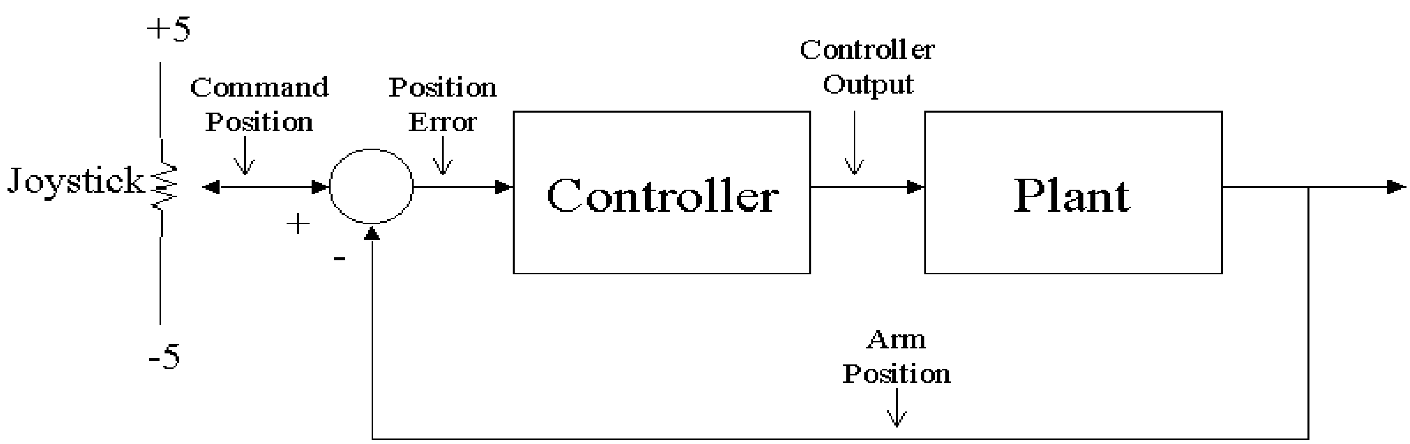
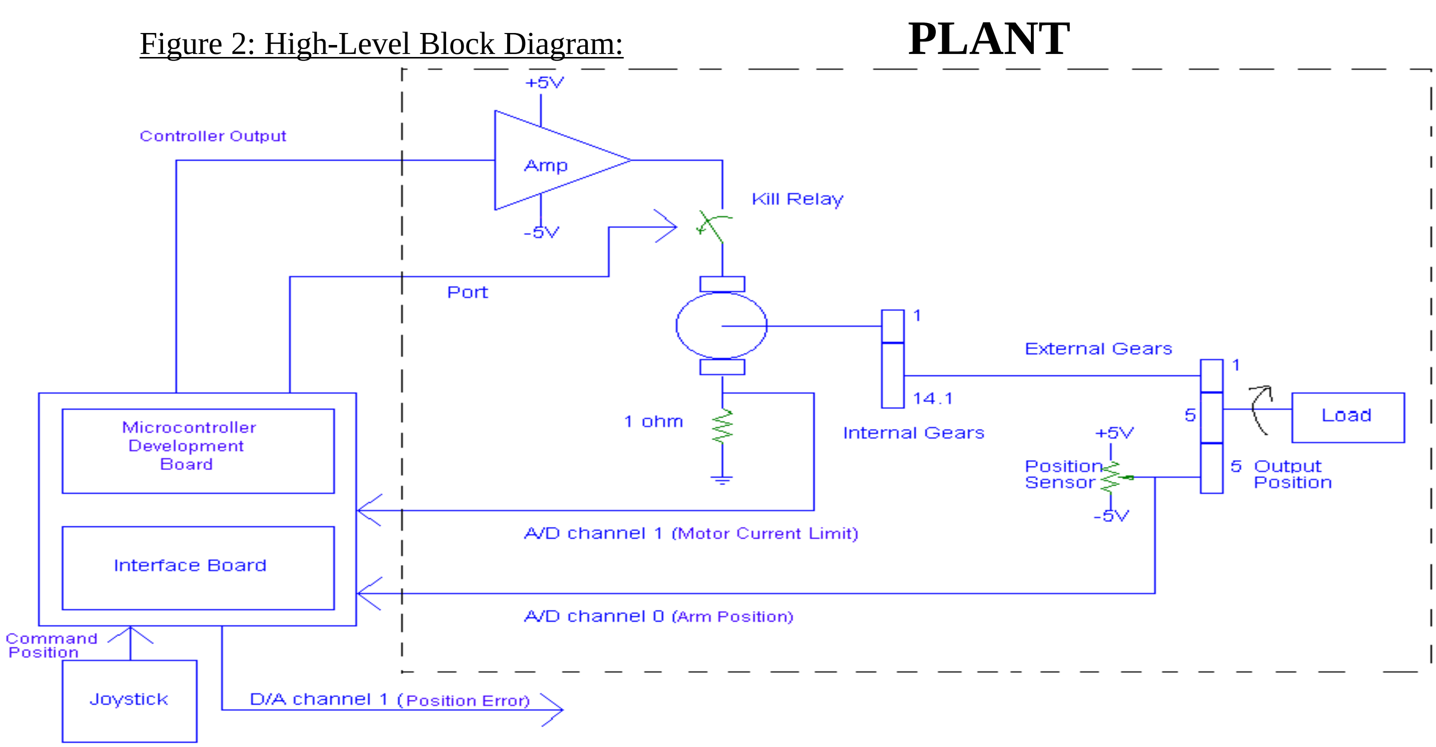


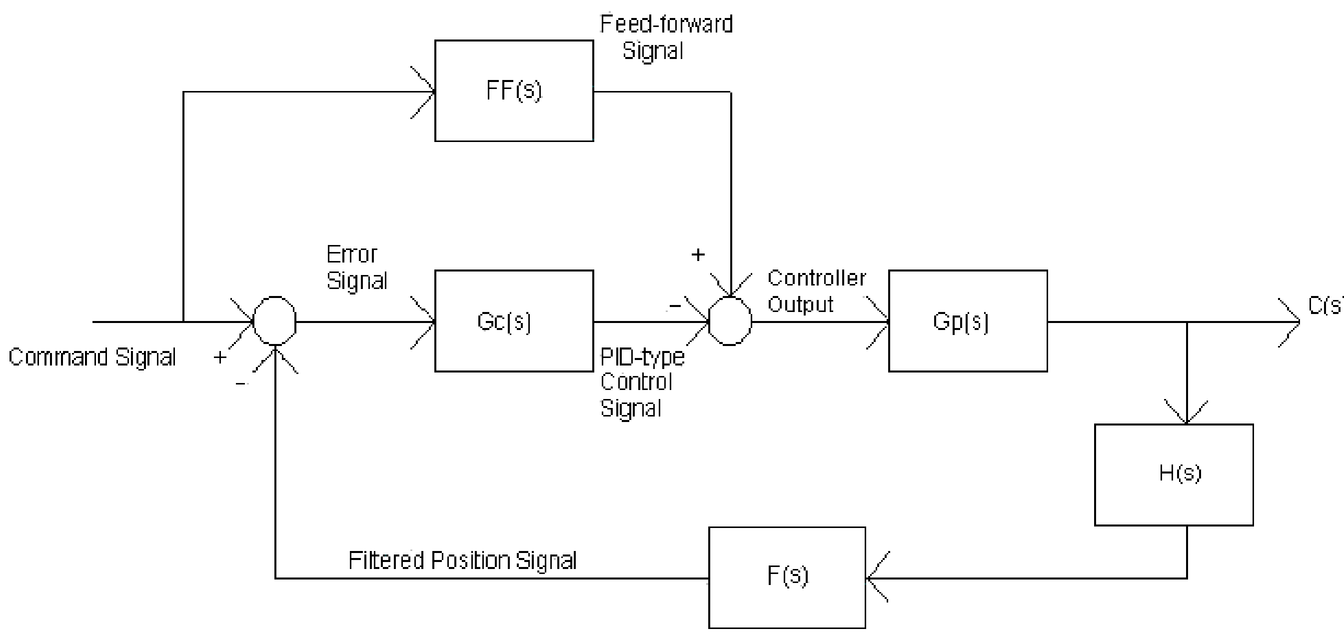
Figure 2: High-Level Block Diagram:



The following signals will be available on the D/A converter output channels. The expanded control block diagram is shown in Figure 3.

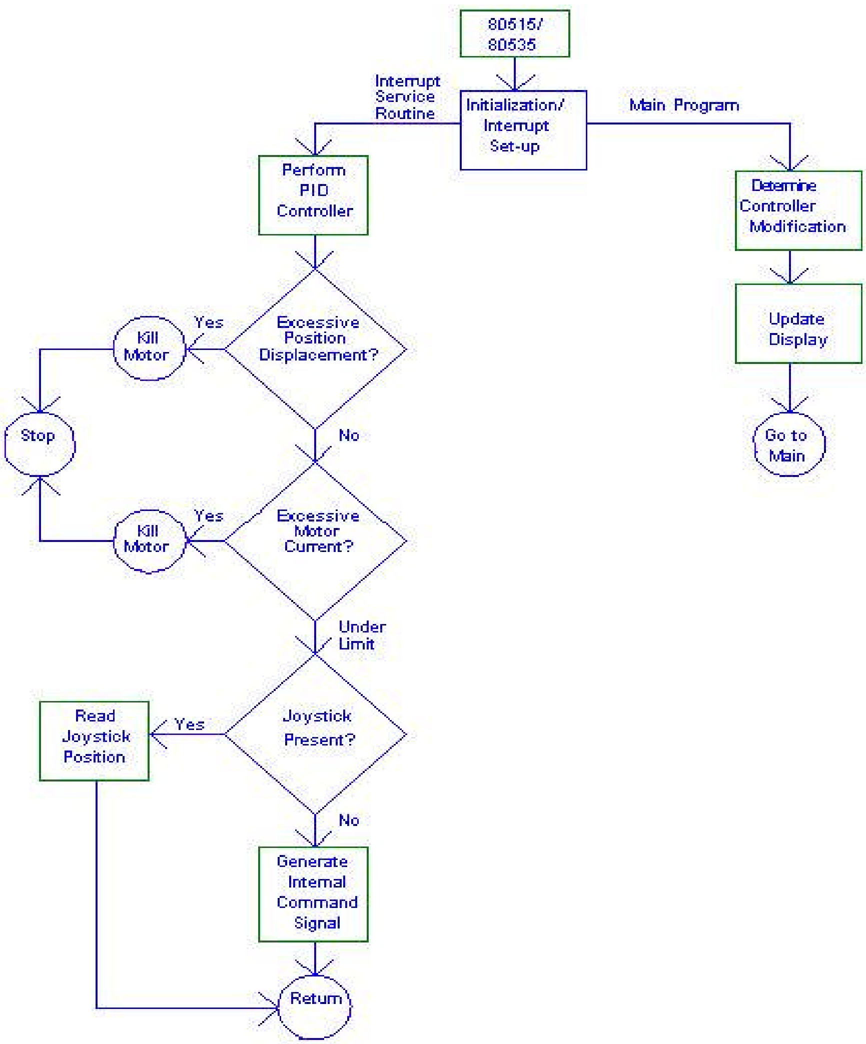
Command position	- Desired robot arm position from joystick or keypad input.
Feed-forward signal	- The output signal from the feed-forward compensator, FF(s).
Error signal	- The difference between the command signal and the filtered position signal.
PID-type controller signal	-The output signal from the PID(proportional+integral+derivative)-type controller, Gc(s).
Controller Output	- Signal that drives the robot arm system, connected to power amplifier.
Filtered position signal	- The filtered actual position sensor signal.
Sensor H(s)	- H(s) = 0.028 volts/degree
Filter F(s)	- Low pass digital filter.
Plant Gp(s)	- Gp = (29.8e^-0.02s)/((s/3.6 + 1) (s/3.6 + 1)) Dead-zone due to static friction was modeled as 20 ms time delay. Note that this is a type 0 system.

<u>Figure 3: Expanded Control System Block Diagram</u>



The software flowchart is shown in Figure 4. The software contains an interrupt service routine as well as the main program. The software will kill the motor if there is excessive position displacement or if the current exceeds its limit. The software also checks to see if the joystick is present. Timer 2 of the 80535 microcontroller will be used to generate the interrupt for the PID controller calculations. Initially, the timer will be set for a 5 millisecond interrupt (200 Hz sampling). This fast sampling time will make the overall system look like a continuous-time system instead of a discrete-time system. Later, the interrupt time will be decreased, but this subject will not covered until the second semester senior year (EE432 Control Theory II). Dr. Dempsey suggested 200 Hz sampling based on previous research. Since type 0 systems have constant error for step inputs, a PID controller is used. A PID controller, when implemented with the plant, leaves the GcGp system as a type 1 system. The steady state error for a type 1 system is equal to zero for step inputs. Feed-forward control is utilized to create a fast transient response region in an attempt to speed up the total system. Ideally, a perfect tracking system is desired, thus F = 1/Gp.

Figure 4: Software Flow Chart



Current Progress:

A user-friendly interface for the robot arm is being designed. Currently, one is able to select the display for the LCD through a keypad input. The different signals which can be displayed on the LCD are arm position in volts, joystick position in volts, arm position in degrees, and not valid if an unused key is pressed. Degree measurement for the arm position is displayed on the LCD from –180° to 180°. The LCD is constantly updated so that the user may observe different signals in the system as they change.

Open-loop control of the robot arm is possible through the use of a joystick. By moving the joystick to the left, the arm moves counter-clockwise and by moving the joystick to the right, the arm moves clockwise. The degree by which the joystick is moved determines the speed that the robot arm moves. There are no limits to the arm position present at this time.

During the Control Theory class, a take home exam was completed which contained a proportional controller for the robot arm system. The design was completed using a desired PM of 40°. The calculated values obtained from the design varied from the desirable values for this system, such as a very large percent overshoot. However, this same procedure for designing the controller will be implemented early in the Spring 2001 semester and will be utilized in the system.

Schedule:

Week(s)	Tasks
1-3	Proportional controller Investigation of unity feedback for the system
4-5	User friendly interface (keypad and LCD) Conversion to C code
6	Current and maximum angle limit protection
7	Display internal signals
8	Further C code conversion
9-11	Proportional-integral and feed-forward controllers C code conversion
Apr. 24th	EXPO

References Cited

[1] Handbook of Intelligent Control- Neural, Fuzzy, and Adaptive Approaches, editors D. White and D. Sofge, Van Nostrand Reinhold, New York, N.Y., 1992.

[2] Neural Networks for Control, editors W. Miller, R. Sutton, P. Werbos, The MIT Press, Cambridge, MA, 1991.

[3] G. L. Dempsey. "ALS 990 Wheel Loader: Controller Design for Bucket and Steering Systems," Technical Report, Caterpillar Inc., Systems and Controls Research Department, November 1996.

[4] J. S. Alig, Investigation of Conventional and Neural Control Methods for Nonlinear Plants, MSEE Thesis, advisor G. L. Dempsey, December 1997.

[5] J. S. Alig and G. L. Dempsey. "Investigation of Anti-windup Control Compensation", Technical Report, Caterpillar Inc., Systems and Controls Research Department, August 1997.

[6] J. S. Alig and G. L. Dempsey. "Investigation of Feed-forward Compensation Methods", Technical Report, Caterpillar Inc., Systems and Controls Research Department, August 1997.