Engineering Technology Feedback Control Laboratory at University of Central Florida

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Abstract

Closed-loop feedback control system is an important component of a well-rounded engineering technology program However, since feedback control systems tends to be a rather complex topic, students react positively to hands-on experiments that assist them visualize control systems in practical situations. and, in today's technology, utilizing and integrating computers within the control loop is essential. An innovative feedback control laboratory has been developed in the department of engineering technology at University of Central Florida to fill this need. The laboratory is equipped with some of the most frequently used control systems in engineering and industry. It is designed to bridge the gap between theory and real-life problems, and to give the students valuable hands-on experience which helps them better prepared for their careers. A number of practical feedback control system experiments are being developed that will allow students an opportunity to develop appropriate transfer functions and control programs for closed-loop system with a computer in the loop.

Introduction

The Department of Engineering Technology at University of Central Florida has been involved in teaching control feedback concepts since its inception. Over the yeas this commitment has evolved into a four-credit upper division course, EET4732. This course introduces analog control systems with the following topics; mathematical modeling and simulation, time and frequency response, stability analysis, analog controller design and implementation, and an introduction to digital control systems in view of greater flexibility of a digital controller[1]. This course was originally taught in a traditional, lecture oriented fashion due to the lack of laboratory equipment. This traditional approach of teaching control systems ignores the gap between theory and reality. No matter what illustrated examples used in text books or lectures, students are only exposed to equations, matrices, block diagrams, frequency response, and signal flow graphs. Even simple systems, such as a single-input, single-output DC motor can be abstract when described only on mathematical terms. Not only do demonstrations and experiments help students better comprehend theoretical concepts, they allow more realistic situation to be examined and understood. Furthermore, control-system hardware under computer control is a necessary component of a student's educational experience while learning about control systems. To accomplish this objective, the following were considered essential ingredients for the EET4732 control feedback laboratory: i) A variety of different types of feedback control system setups are needed to expose students to a broad range of control-system requirements and approaches, etc. ii) As previously mentioned, each system should be under the control of a computer. iii) Each system must provide physical and visual output so that students can easily see and understand the performance and effects of changing control algorithms. iv) Because of limited funds, each system must be economical and relatively easy to develop. v) Each system must be easy and fun to use, while providing educational sound principles of computer-controlled closed-loop feedback control. Based on these reasons, a control feedback laboratory was established and the course was changed from three-credit to four-credit course. A number of commercially-available control system trainers were investigated. The decision was made to equip This laboratory with two SFT154 position and speed analog/digital control systems from Feedback Inc.[2], analogue computing module, ACM349, consisting of op-amps and resistors and capacitors, for real-time analog simulation from Feedback Inc., 80486 PC's, data interface boards, power supplies, signal generators, and oscilloscopes. This laboratory has several unique features. First, Analog computers with five integrators are used to perform real-time simulation after the system is modeled. Second, the SFT154 position and speed control system is used as the primary hardware device to be modeled and controlled, in both analog and digital. It generates responses that can be adequately modeled by a first order or second order transfer function with several nonlinearities, such as friction. This has the advantage of exposing students to real-world effects that can potentially tamper control system performance. Since the intention in this laboratory is to illustrate and give students hands-on experience to real world control systems, the SFT154 position and speed control system is the best candidate for this purpose.

Overview of Current Laboratory Experiments

Currently, the control feedback systems for EET4732 include the following experiments, using both hardware and software (104 page-laboratory manual):

1) General System Information and Introduction (how to use the software package)
2) Laboratory Report Format
3) Experiment #l- A/D and D/A Conversion Concepts
4) Experiment #2- Motor Control
5) Experiment #3- Analog Shaft Position Sensing
6) Experiment #4- Digital shaft Position Sensing
7) Experiment #5- Positional Control Loops
8) Experiment #6- Speed Control Loops
9) Experiment #7- PID Control
10) Experiment #8 What is Analogue Computing
11) Experiment #9 The Integrator
12) Experiment # 10 First Order Differential Equations
13) Experiment #l1 Second Order Differential Equations
14) Experiment #12 Effects of Negative and Positive Damping
15) Experiment #13 Frequency Response of a Second-Order System

A brief description of each experiment is given below followed by discussion of position and speed control of SFT154.

Experiment 1 - A to D and D to A Concepts

1. A Simple A to D System
2. A to D Displayed as XY plot
3. Mathematical Generation of Waveshapes

Experiment 2 - Motor Control

1. Using the D/A output and the computer to control the motor voltage
2. Applying a step to the motor and measuring the motor response with the tachometer connected

3. Investigating the motor response at different drive levels

Experiment 3 - Analog Shaft Position Sensing

1. Using the A/D input and the input potentiometer
2. Using the A/D input and the output shaft potentiometer with the motor rotating

Experiment 4 - Digital Shaft Position Sensing

1. Using an absolute encoder with Gray code
2. Using an incremental encoder with a two phase track
3. Using the incremental encoder to measure shaft speed and direction

Experiment 5 - Positional Control LOOPS

1. A positional servo using proportional control and an analog sensor
2. A positional servo using proportional control and a digital sensor

Experiment 6 - Speed Control LOOPS

1. A speed control system using an analog sensor
2. A speed control system using a digital sensor

Experiment 7 - PID Control Practicals

1. Proportional Control with Derivative Action
2. Proportional Control with Integral Action
3. Proportional Control with Derivative and Integral Action

Experiments (8-13) Real-Time Simulation

In experiments 8-13, the real-time simulation using analog computer and frequency response are introduced

The SFT154 Position Control System

a. Using potentiometer sensor

In this experiment the computer is used, together with the potentiometer sensor, to make a simple closed loop position control system A triangular signal with peak value of 5 volts and a slope of 2 is used to provide an input to the system that the output shaft attempts to track. The input is called the set value and the A/D converter sends this to the computer [3]. The actual position of the shaft (the measured value) is sensed by the potentiometer and this is also sent to the computer via the same A/D converter using a controlled switch to multiplex the A/D input. The difference between the two inputs (called error) is calculated and the result used to drive the motor via the D/A converter. In order for the error to be small the error must be magnified so that small errors still correct the output ; this magnification factor is called gain. The gain value has a large effect on the behavior of the system and too much or too little both cause problems. The experiment will show both these effects. Figure 1 shows how the system blocks are configured for this experiment.

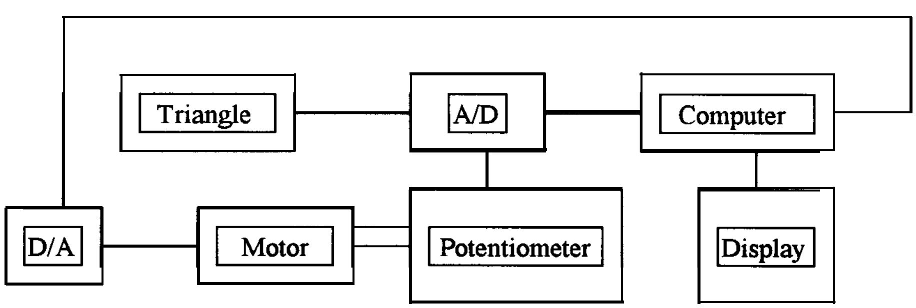

Figure 1. Block diagram of the SFT154 potentiometer position control

b. Using digital encoder

Assignment 4 introduced the use of a rotary shaft encoder as a method of measuring position. This experiment shows that a positional servo control system can be implemented using a digital shaft encoder instead of the potentiometer and A/D converter. The concept is the same as in Experiment 1, the only difference is that the measured value is derived from the absolute shaft encoder with Gray code. The triangular waveform is used as the input which causes the motor to turn back and forth about zero. The input signal is displayed on the computer screen along with the error signal or the measured position output from the shaft encoder. The resolution of the measured value is limited to the number of tracks on the encoder disc. The encoder has six tracks, so the resolution is 2*6 = 64 levels. This results in the measured value having a more stepped appearance. The diagram of Figure 2 shows how the system blocks are connected for this experiment.

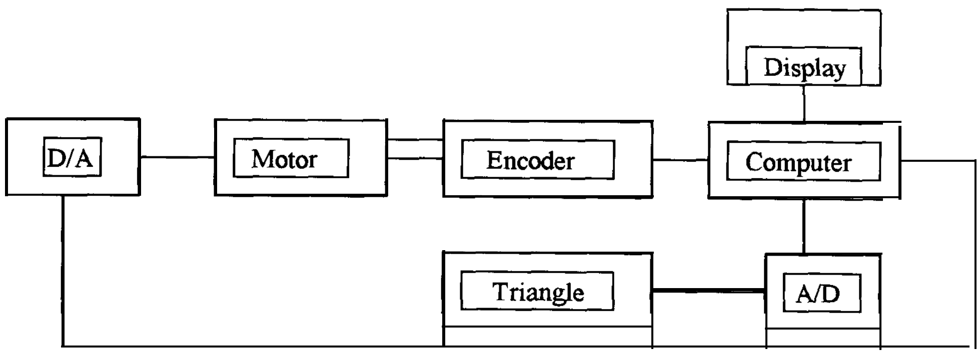

Figure 2. Block diagram of the SFT154 shaft encoder position control

To study the stability, transient and steady state responses, sampling time of 0.5 msec is used. The motor/gear transfer function, G,,,(s) and the sensor transfer function H(s) are obtained through an experiment; G,,,(s) = 20/s(s+4), H(s) = 0.6.Z-transformation of G,,,(s) and D/A yields the following discrete transfer function for the system

$$G(z) = \frac{27.44\times 10^{-7}(z + 0.9992)}{(z-1)(z-0.9923)}$$

Case 1 (no controller).

The system is tested without a controller. The transient response is satisfactory compared to the theoretical calculation, the rising portion of the actual and expected responses shows that they are very close. This indicates that the mathematical model obtained for the system is accurate. However, the steady-state response is unsatisfactory, the steady state error is quite large, e_{ss} = 0.582 volts, this is equivalent to approximately 10 degrees of steady-state error in the SFT154.

Case 2 (with a controller).

To reduce the steady-state error, a proportional-integral-derivative (PID) controller is considered. The transfer function for the PID controller is':

$D(z) = K_p + 0.5K_I T [(z+1)/(z-1)] + K_D, [(z-1)/Tz]$

where T is the sampling time, 0.5 msec. The reason for selecting a PID controller is that it increases the system from a type- 1 system to a type-2 system (PID has a pole at Z = l), hence totally eliminating the steady-state error. It should be clear from the above equation that a PID controller includes two poles and two zeros. The poles are located at z = 0 and z = 1, while the location of the zeros depends on the selection of the three parameters K_p, K_I, and K_D. Root locus technique[4] is used to design the PID controller for the system. The root locus plot of the system without a PID controller is shown in Figure 3. With controller considered, the two zeros are selected to be z = 0.9953 and z = 0.9964. The three parameters are then $K_p= 10$, $K_I= 1.05$, $K_D=4$. Figure 4 shows the root locus plot with the PID controller. The time response of SFT154 without the controller is shown in Figure 5. Figure 6 shows the time response of the system with the PID controller. The theoretical calculations and the actual time response of the system output are very close. Moreover, the steady-state error (e_{ss}) is zero as expected and the overshoot is insignificant.

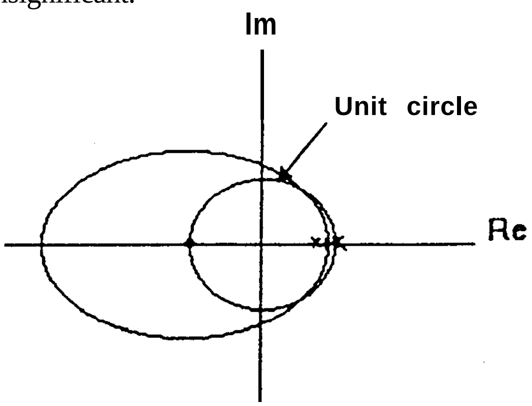

Figure 3. The root locus without a PID controller

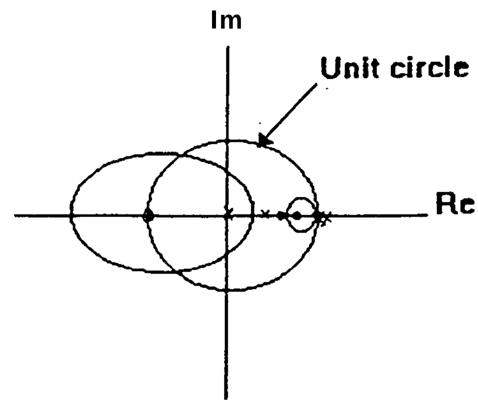

Figure 4. The root locus plot with a PID controller.

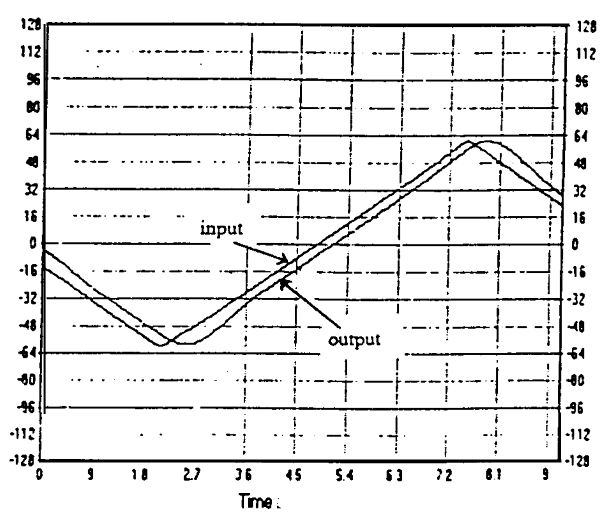

Figure 5. Time response without a PID controller

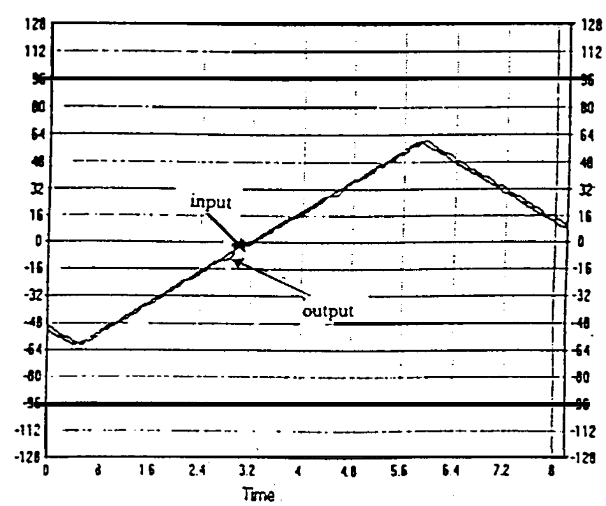

Figure 6. Time response with a PID controller

The SFT154 Speed Control

The Analysis and design of speed control of the SFT154 system is essentially similar to position control except that G,,,(s) = 20/(s+4), and H(s) = 0.2. It should be clear that the system is now *type 0* instead of *type 1*, and finite steady-state error does exist for a unit step input. The design of the PID controller for speed control system is performed in a similar fashion to position control design using digital root locus technique and thus omitted in this paper.

Conclusion

This paper has presented an overview of the laboratory experiments currently in use by the Engineering Technology Department at University of Central Florida. It has also described the closed-loop system analysis and design techniques using SFT154 system to illustrate the fundamentals of control to our students

References

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