
AC 2011-490: A STUDENT-ORIENTED CONTROL LABORATORY USING PROGRAM CC

Ziqian Liu, SUNY Maritime College

Ziqian Liu received the Ph.D. degree from the Southern Illinois University Carbondale in 2005. He is currently an Assistant Professor with the Engineering Department, SUNY Maritime College. From 2005 to 2008, he worked in Ingersoll-Rand Co. Ltd, USA. From 1989 to 1999, he was with the Department of Electrical Engineering, Hefei University of Technology, China. His research interests include nonlinear optimal control, intelligent control, motor control systems, DSP or microprocessor-based embedded systems, power electronics and drives, and computational modeling.

A Student-Oriented Control Laboratory Using Program CC

Abstract

Control course is a classic but also a difficult course in engineering education. Its traditional laboratory components usually are made up of using analog devices to simulate control systems, which lack the emphasis on the soft side of intelligent control design skills. In order to well prepare our engineering students for the challenges presented by advanced technologies in the 21st century, a student-oriented control laboratory has been developed in the SUNY Maritime College for a senior control course. We adopted Windows XP based software, Program CC, in our laboratory. Program CC is a powerful tool for efficiently and effectively developing sophisticated control systems in a wide range of applications. In the laboratory, a series of eight application projects were elaborated, which include the following design themes: ship control system, submarine depth control system, DC motor control system, machine tool control system, automotive power train control system, PID controllers, aircraft control system, and satellite-tracking antenna control system. Through the above hands-on projects, students not only learned how to design, analyze and synthesize a control application system, but also strengthened their understanding of theoretical and abstract subjects in control theory. With the feedbacks from students, we are confident that our newly developed laboratory made contributions in enhancing student intelligent control design skills on the soft side, which is highly demanded for a 21st century and future engineer.

I. Introduction

Control course is a classic but also a difficult course in engineering education. With the energy saving revolution in progress, it is playing a more important role in engineering curriculum. Since a control course mainly focuses on theoretical and abstract subjects, it is very challenging for an instructor to attract and keep our students' interest when teaching it. Active learning is an effective pedagogy to support student learning. It involves providing opportunities for students to meaningfully talk and listen, write, read, and reflect on the content, ideas, issues, and concerns of an academic subject¹. There are various strategies for active learning, and hands-on laboratory is one of them. Hands-on laboratory not only can reinforce theoretical concepts delivered during lectures, but also can give students opportunities to put theory into practice. Furthermore, laboratory exercises provide a sense of accomplishment to students and allow room for their creativities. As Confucius's aphorism states²: *I hear and I forget. I see and I remember. I do and I understand.*

On the other hand, traditional laboratory components usually are made up of using analog devices to simulate control systems, which lack the emphasis on the soft side of intelligent control design skills. In order to well prepare our engineering students for the challenges presented by advanced technologies in the 21st century, a student-oriented control laboratory has been developed in the SUNY Maritime College for a senior control course. We adopted Windows XP based software, Program CC, in our laboratory. Program CC is a computer-aided control system analysis and design program used in industries, research institutions, colleges and universities around the world³. It provides a powerful tool for efficiently and effectively

developing sophisticated control systems in a wide range of applications. It implements a broad range of control system design methods from Bode to Root Locus to Linear Quadratic Optimal Control. Its graphics and design methods are implemented by using high level, user-friendly functions. In addition, Program CC provides a free student download version, which can be used by students on their own computers, away from the university laboratories.

In our student-oriented control laboratory, a series of eight application projects were elaborated. The themes of our lab projects include the following designs: ship control system, submarine depth control system, DC motor control system, machine tool control system, automotive power train control system, PID controllers, aircraft control system, and satellite-tracking antenna control system. Through the above hands-on projects, students not only learned how to design, analyze and synthesize a control application system, but also strengthened their understanding of theoretical and abstract subjects in control theory. With the feedbacks from students, we are confident that our newly developed laboratory made contributions in enhancing student intelligent control design skills on the soft side, which is highly demanded for a 21st century and future engineer.

In the following sections, we will discuss some of our laboratory projects. In Section II, we present the design project of ship control system. In Section III, we describe the design project of aircraft control system. In Section IV, we illustrate the design project of satellite-tracking antenna control system. In Section V, we show the project of PID controller design. Finally, we give some discussions in section VI.

II. Design of Ship Control System

Laboratory description: Consider the 270-ft U.S. Coast Guard cutter Tampa (902) shown below. Parameter identification based on sea-trials data was adopted to estimate the hydrodynamic coefficients in the equations of motion⁴. The result is that the response of the heading angle of the ship ψ to rudder angle δ and wind change w can be described by the following transfer functions

$$G_{\delta}(s) = \frac{\psi(s)}{\delta(s)} = \frac{-0.0184(s + 0.0068)}{s(s + 0.2674)(s + 0.0063)},$$

$$G_w(s) = \frac{\psi(s)}{w(s)} = \frac{0.0000064}{s(s + 0.2674)(s + 0.0063)},$$

where

- ψ = heading angle, rad,
- ψ_r = reference heading angle, rad
- $r = \dot{\psi}$ yaw rate, rad/sec
- δ = rudder angle. Rad
- w = wind speed, m/sec.

Laboratory assignment: Using Program CC:

- (1) To investigate the relationship between the yaw rate r and the rudder angle δ , determine the settling time of r for a step change in δ , and make a plot.
- (2) To investigate the relationship between the heading angle ψ and the wind speed w , and plot the response of heading angle for a wind gust of 10 m/sec.

Explanation about this laboratory: this project is designed to aid students in understanding and mastering the important concepts, and acquiring the corresponding skills as listed below:

- Be familiar with the computer-aided control system design tool, Program CC.
- Recognize that transfer functions can describe the dynamic behavior of a ship control system.
- Know how to obtain the characteristics of transient response for a control system.

The program CC graphic solutions are given in the following figures. Figure 1 shows the response of the yaw rate of the ship to a step change in rudder angle. Figure 2 shows the response of the heading angle of the ship to a wind gust of 10 m/sec.

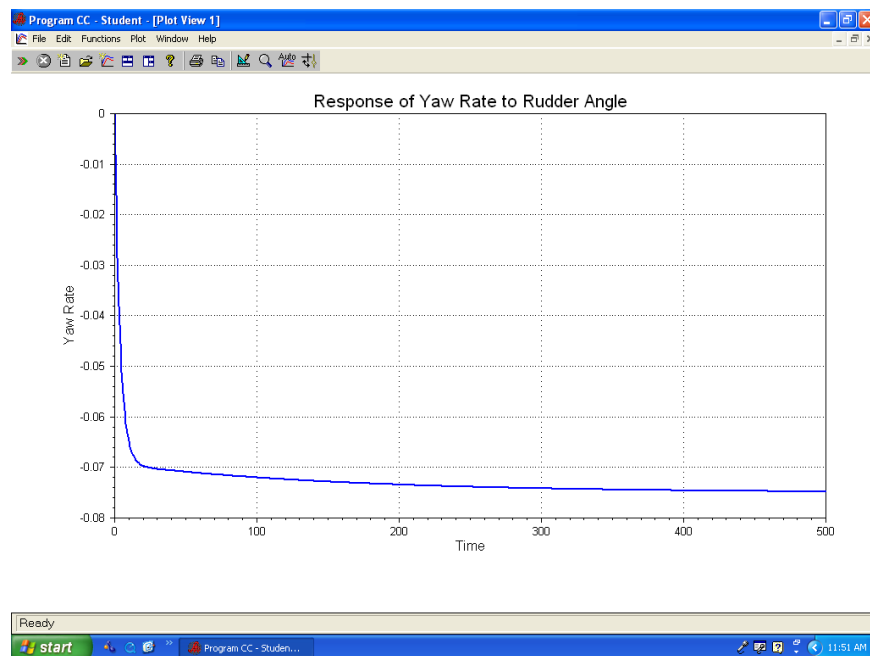


Figure 1 Response of yaw rate to rudder angle

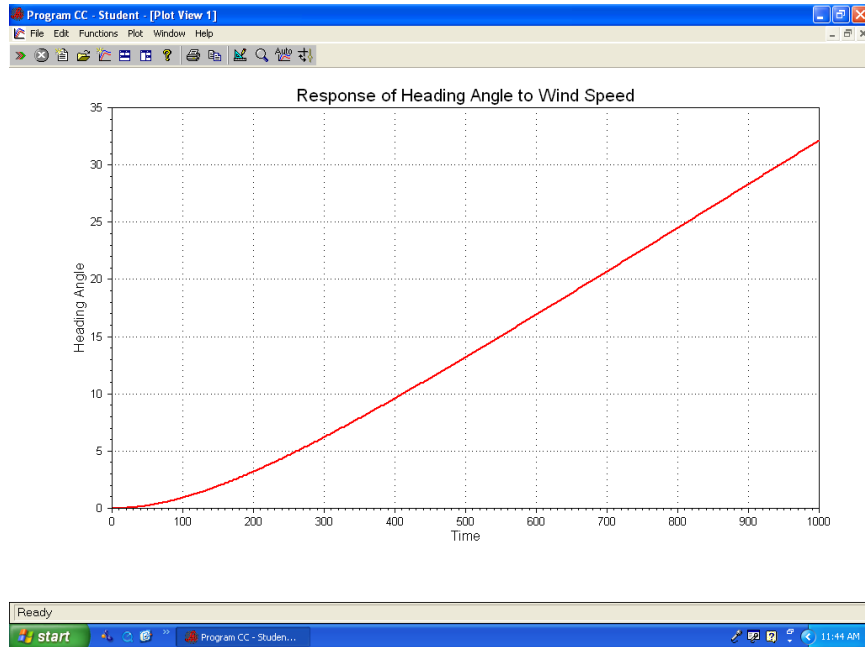


Figure 2 Response of heading angle to wind speed

III. Design of Aircraft Control System

Laboratory description: The goal of vertical takeoff and landing (VTOL) aircraft is to achieve operation from relatively small airports and yet operate as a normal aircraft in level flight. An aircraft taking off in a form similar to a missile (on end) is inherently unstable. A control system using adjustable jets can control the vehicle⁵. The dynamics of a jump-jet aircraft can be represented by an open-loop transfer function shown in Figure 1.

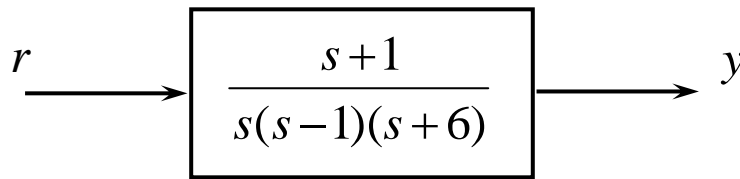


Figure 1 A jump-jet aircraft system

Laboratory assignment:

Part 1. For the open-loop control system described by the above block diagram, use Program CC to plot unit step response of the system output $y(t)$.

Part 2. Consider the closed loop control system shown in Figure 2

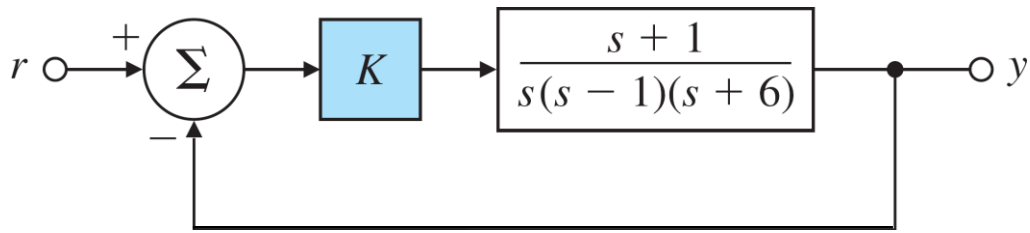


Figure 2 Closed loop control system

where K is the gain of the proportional controller. Use Program CC to plot unit step response of the system output $y(t)$ for the following three cases:

Case1: $K = 24$

Case2: $K = 12$

Case3: $K = 6$

and compare the differences among them.

Part 3. Compare the results in part 1 and part 2, what are your conclusions? **After you complete the above three parts, please write and submit an individual lab report in two week.**

Explanation about this laboratory: this project is designed to aid students in understanding and mastering the important concepts, and acquiring the corresponding skills as listed below:

- Understand the concept of stability and how important it is for a dynamic system.
- Know how to obtain transient responses by using Program CC.
- Be aware of constructing a feedback control to let an unstable system become a stable system.

The program CC graphic solutions are given in the following figures. Figure 3 shows the response of the jump-jet for an open-loop control system, which is unstable. Figure 4 shows the responses of the jump-jet for a closed-loop feedback control system under different control parameters.

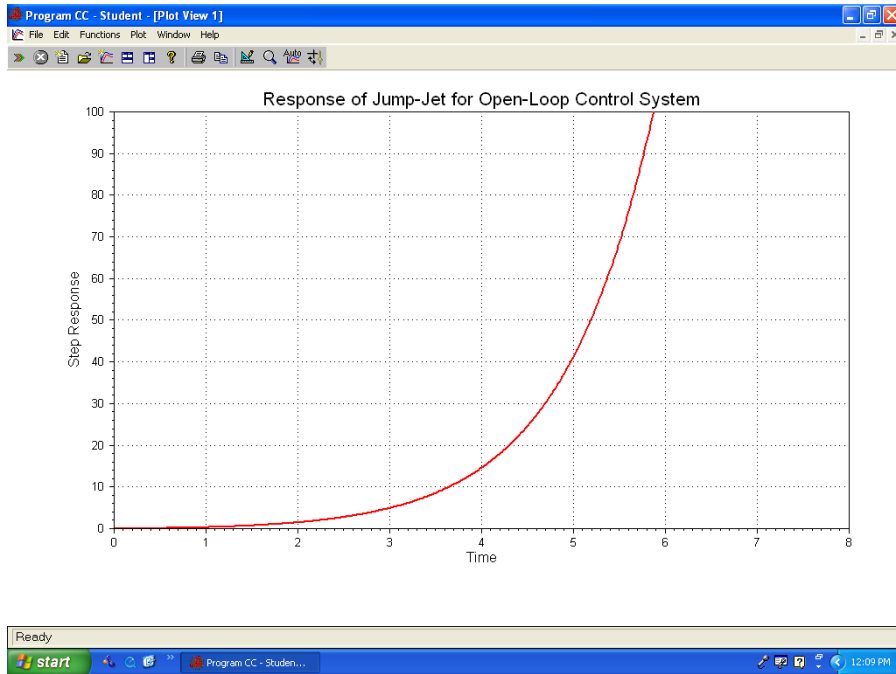


Figure 3 Response of jump-jet for open-loop control system

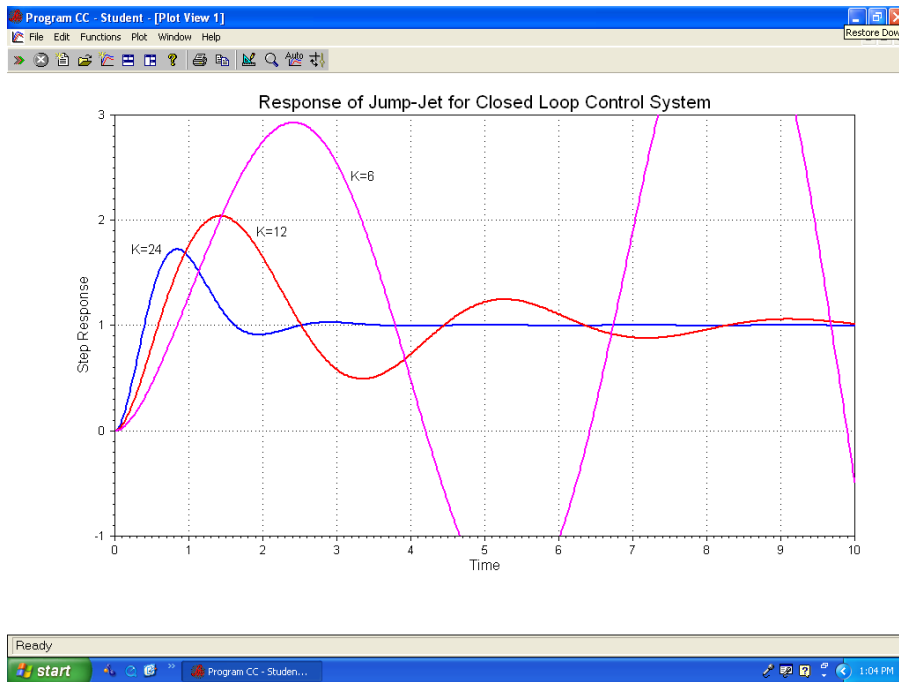


Figure 4 Responses of jump-jet for closed loop control system

IV. Design of Satellite-Tracking Antenna Control System

Laboratory description: You wish to control the elevation of the satellite-tracking antenna shown below. The antenna and drive parts have a moment of inertia J and a damping B ; these arise to

some extent from bearing and aerodynamic friction, but mostly from the back emf of the DC drive motor⁴. The equation of motion is

$$J\ddot{\theta} + B\dot{\theta} = T_c$$

where $J = 600000 \text{ kg}\cdot\text{m}^2$, $B = 20000 \text{ N}\cdot\text{m}\cdot\text{sec}$, and T_c is the torque from the drive motor. Now the applied torque is computed so that θ tracks a reference command θ_r according to the feedback law

$$T_c = K(\theta_r - \theta)$$

where K is the feedback gain.

Laboratory assignment: Using Program CC:

- (1) Find the maximum value of K that can be used if you wish to have an overshoot $M_p < 10\%$?
- (2) Plot the step response of the antenna system for $K = 200, 400, 1000,$ and 2000 .

Explanation about this laboratory: this project is designed to aid students in understanding and mastering the important concepts, and acquiring the corresponding skills as listed below:

- Understand the important role of modeling in the control system design process.
- Be aware of the central role of error signals in analysis of control systems.
- Know how to obtain transient responses by using computer-aided design tool.

The program CC graphic solutions are given in the following figures. Figure 5 shows the step response of the antenna system for feedback gain $K = 200$. Figure 6 shows the step response of the antenna system for feedback gain $K = 400$. Figure 7 shows the step response of the antenna system for feedback gain $K = 1000$. Figure 8 shows the step response of the antenna system for feedback gain $K = 2000$.

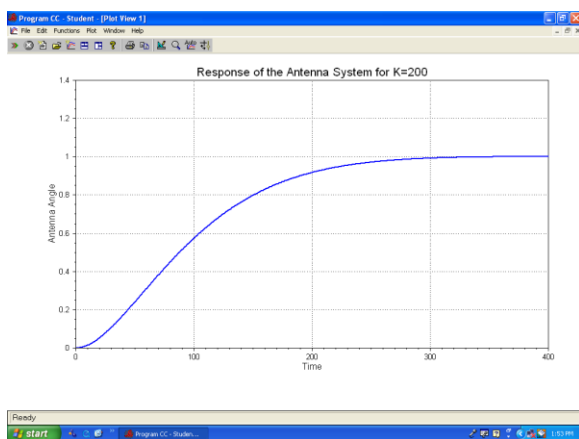


Figure 5 Response of the antenna system for $K = 200$

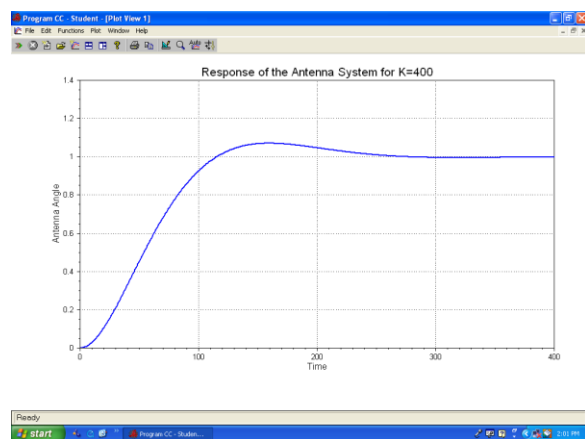


Figure 6 Response of the antenna system for $K = 400$

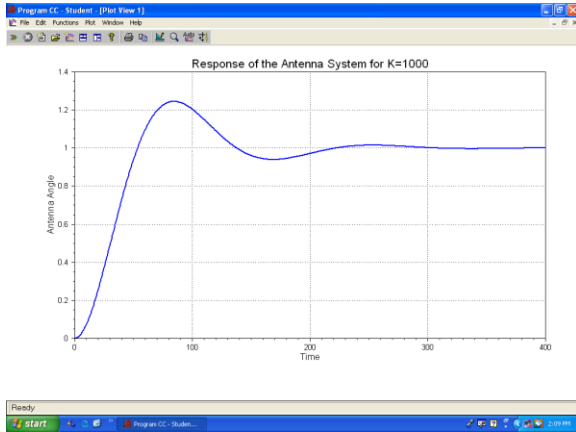


Figure 7 Response of the antenna system for $K = 1000$

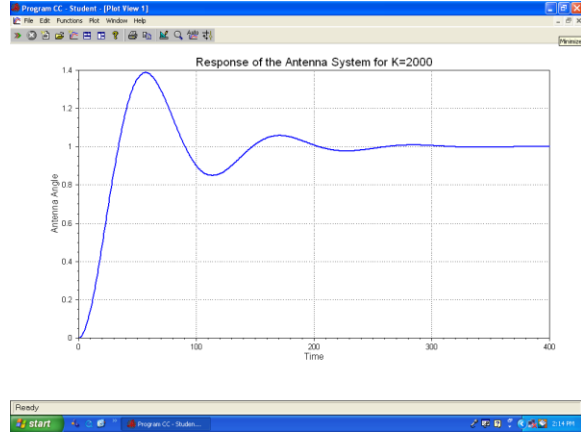


Figure 8 Response of the antenna system for $K = 2000$

V. Design of PID Controllers

Laboratory description: The speed control of a high-speed train is represented by the system shown in Figure 10. The transfer function of the train dynamics is shown in Figure 9.

$$G(s) = \frac{1}{s^2 + 10s + 20}$$

Laboratory assignment:

Part A. For the open-loop system described by the following block diagram, assume that the input $r(t)$ is a unit step. (1) Compute the steady-state system output y_{ss} . (2) Find the steady-state error e_{ss} . (3) Make a plot for the system output $y(t)$ by using Program CC.

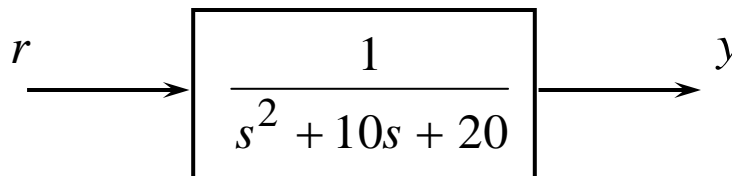


Figure 9 A high speed train system

Part B. Consider the closed loop control system shown below, where $D(s)$ is a PID controller. Assume that the input $r(t)$ is a unit step. Determine the steady-state error and use Program CC to plot the response of the system output $y(t)$ for each of the following cases:

- (1) Use **P** control, let $D(s) = K_p$, in which (a) $K_p = 30$, (b) $K_p = 300$, and (c) $K_p = 1000$.

- (2) Use **PI** control, let $D(s) = K_P + \frac{K_I}{s}$, in which (a) $K_P = 300$ and $K_I = 10$, (b) $K_P = 300$ and $K_I = 100$, and (c) $K_P = 300$ and $K_I = 300$.
- (3) Use **PD** control, let $D(s) = K_P + K_D s$, in which (a) $K_P = 300$ and $K_D = 10$, (b) $K_P = 300$ and $K_D = 500$, and (c) $K_P = 300$ and $K_D = 1000$.
- (4) Use **PID** control, let $D(s) = K_P + \frac{K_I}{s} + K_D s$, in which (a) $K_P = 30$, $K_I = 10$, and $K_D = 10$, (b) $K_P = 300$, $K_I = 100$, and $K_D = 500$, and (c) $K_P = 1000$, $K_I = 300$, and $K_D = 1000$.

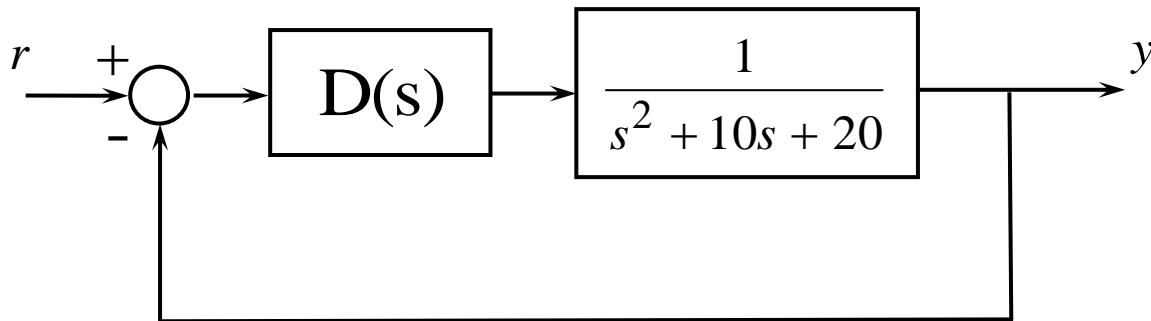


Figure 10 PID closed loop control system

Part C. Compare all results in Part A and Part B, what are your conclusions? **After you complete the above three parts, please write and submit an individual lab report in two weeks.**

Explanation about this laboratory: this project is designed to aid students in understanding and mastering the important concepts, and acquiring the corresponding skills as listed below:

- Be familiar with the PID controller, which is a key element of many feedback control systems used today.
- Understand the differences between the transient response and the steady-state response for a dynamic system.
- Know how to obtain transient responses by using computer-aided design tool.

The program CC graphic solutions are given the following figures. Figure 11 shows the responses of P control feedback system with $K_p = 30, 300$, and 1000 . Figure 12 shows the response of PID control feedback system with $K_p = 30, K_i = 10$, and $K_d = 10$.

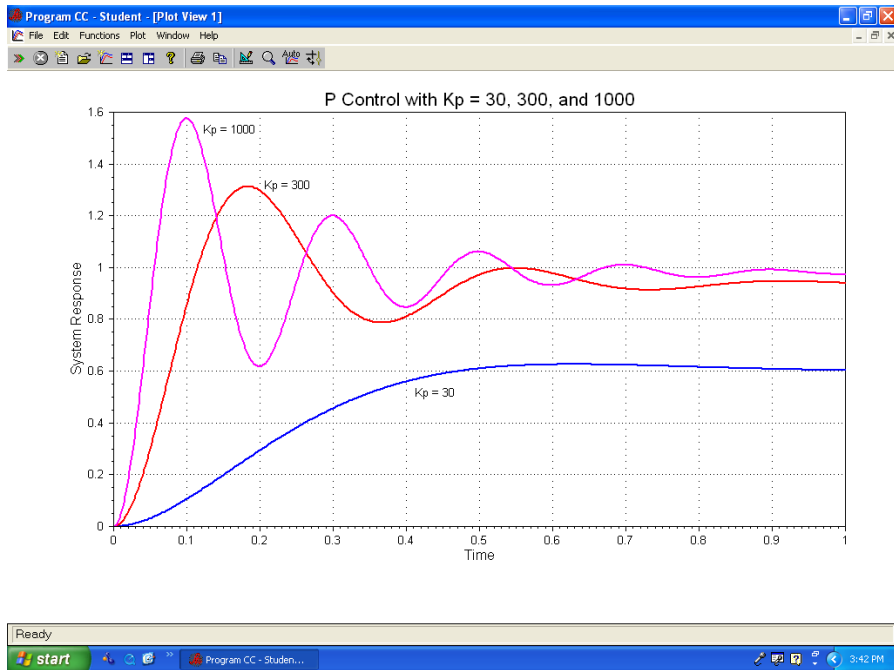


Figure 11 Responses of P control feedback system with $K_p = 30, 300, \text{ and } 1000$

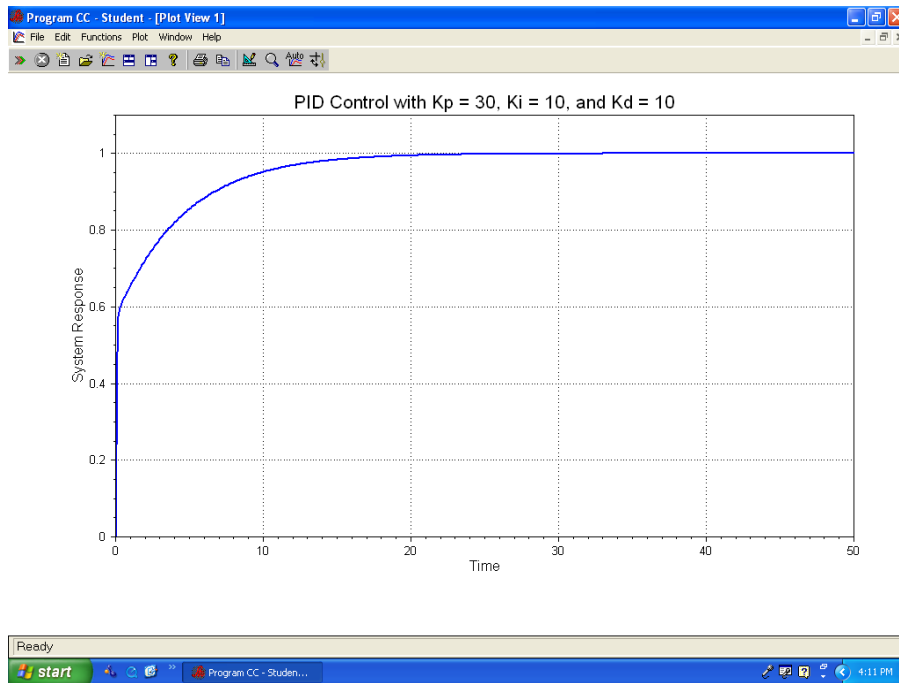


Figure 12 Response of PID control feedback system with $K_p = 30, K_i = 10, \text{ and } K_d = 10$

VII. Conclusions

In this paper, we presented the design of a series of application projects for a student-oriented control laboratory using Program CC in a senior control course. By asking students to do soft-

side hands-on laboratory and develop their own solutions for the lab projects, we give students opportunities to put theory into practice, which also keep students' interest high. Furthermore, the laboratory exercises provide a sense of accomplishment to the students and allow room for their creativities.

Bibliography

1. C. Meyer and T. B. Jones, "Promoting active learning: Strategies for the college classroom" 1993, San Francisco: Jossey-Bass.
2. <http://learningforlife.fsu.edu/ctl/explore/onlineresources/docs/Chptr8.pdf>
3. Program CC Official Website: <http://www.programcc.com>
4. G. F. Franklin, J. D. Powell, and A. Emami-Naeini, *Feedback Control of Dynamic Systems*, 5th Ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2008.
5. R. C. Dorf and R. H. Bishop, *Modern Control Systems*, 11th Ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2008.