University of Louisiana at Lafayette

Control Systems

MCHE 474

Lab 4

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G = Plant function
s = Laplace Domain variable
PID = Proportional-Integral-Derivative Controller
KP = Proportional Gain
KI = Integral Gain
KD = Derivative Gain

Introduction

This lab was conducted using MATLAB in order to analyze control systems. The plant function for the second order system analyzed in this lab is given, and is shown in Equation 1. The main aspect of the system analyzed in this lab is the effect of a proportional, integral, and derivative control (PID controller).

$$G = \frac{50}{s^2 + 30s + 75} \tag{1}$$

Theory

A PID is a feedback controller which accounts for not just one state of error, but three, in order to modify the input to the system to achieve the desired state. The equation for a PID controller is shown in Equation 2, and is rewritten in Equation 3.

$$PID = KP + KI/S + KDS \tag{2}$$

$$PID = (KDS^2 + KPS + KI)/S \tag{3}$$

The effect of the proportional, integral, and derivative components of the controller are weighted by their gains KP, KI, and KD respectively. Adjusting these gains allows for the PID controller to be tailored to fit the system and the desired performance. Adjusting the proportional gain changes how intensely the controller reacts to error. Adjusting the integral gain changes how quickly accumulated error is accounted for by increasing the controller output. Adjusting the derivative gain changes how quickly the controller reacts to a change in the rate of error change, which is useful for situations where the error changes signs frequently (like an autonomous vehicle which needs to stick to a straight course).

In general, an increase in KP results in a decrease in rise time, increase in overshoot, and a decrease in steady-state error. An increase in KI results in a decrease in rise time, increase in overshoot, and an elimination of steady-state error (because the integral component adjusts the controller output to overcome and error that is failing to change) at the cost of an increase in settling time. An increase in KD results in a decrease in overshoot and a decrease in settling time.

Procedure & Analysis

The system was simulated in MATLAB and a PID controller was implemented. First values of $KP = 1$, $KI = KD = 0$ were used for the controller. The KP was then changed to values of 2 and 10. The system responses for all three combinations are shown in Figure 1. The system characteristics of each combination are shown in Figure 2 through Figure 4. Notice that the increase in KP causes an increase in amplitude and overshoot.

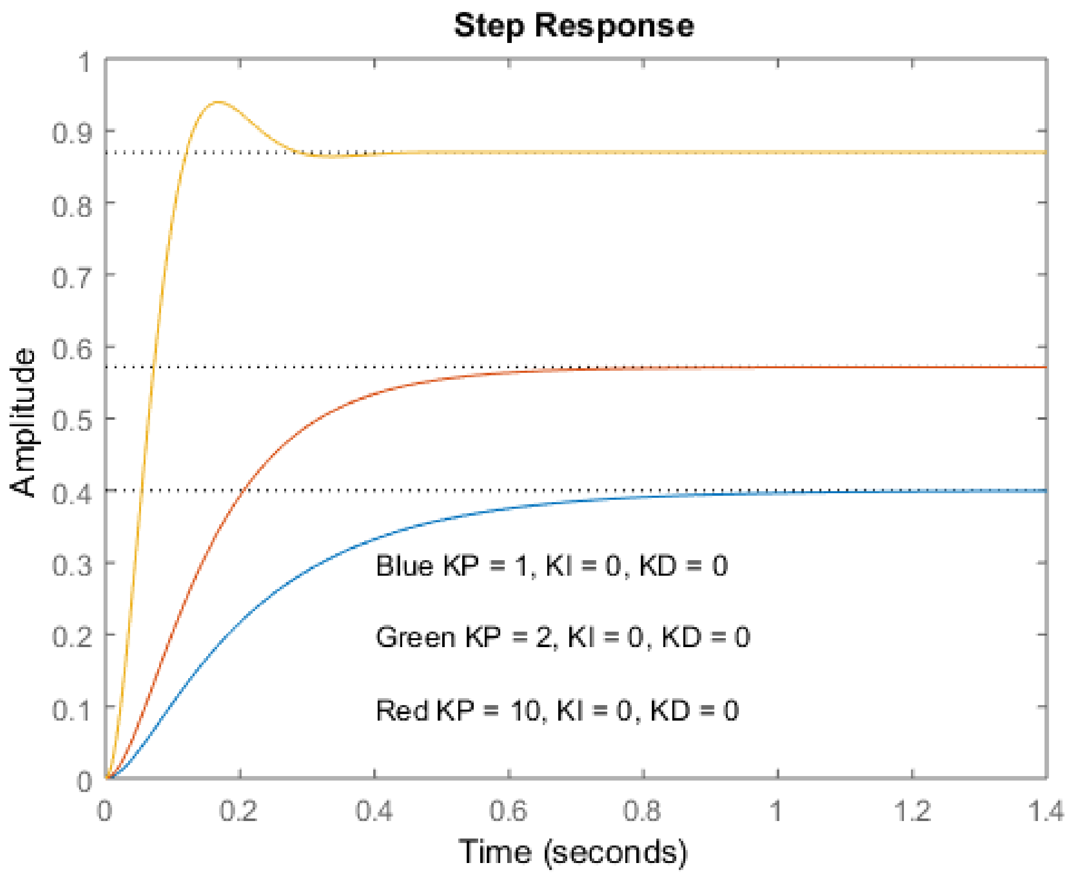

Figure 1: Varying KP System Response

```
    RiseTime: 0.4545
SettlingTime: 0.8270
 SettlingMin: 0.3606
 SettlingMax: 0.3997
   Overshoot: 0
  Undershoot: 0
        Peak: 0.3997
    PeakTime: 1.4700
```

Figure 2: $KP = 1$, $KI = KD = 0$

```
    RiseTime: 0.3050
SettlingTime: 0.5495
 SettlingMin: 0.5144
 SettlingMax: 0.5711
   Overshoot: 0
  Undershoot: 0
        Peak: 0.5711
    PeakTime: 0.9974
```

Figure 3: $KP = 2$, $KI = KD = 0$

```
    RiseTime: 0.0800
SettlingTime: 0.2496
 SettlingMin: 0.7857
 SettlingMax: 0.9396
   Overshoot: 8.0530
  Undershoot: 0
        Peak: 0.9396
    PeakTime: 0.1689
```

Figure 4: $KP = 10$, $KI = KD = 0$

Second, values of $KP = 1$, $KI = KD = 0$ were used for the controller. The KI was then changed to values of 10 and 30. The system responses for all three combinations are shown in Figure 5. The system characteristics of each combination are shown in Figure 6 through Figure 8. Notice that the increase in KI causes an increase in overshoot and settling time, while decreasing the rise time.

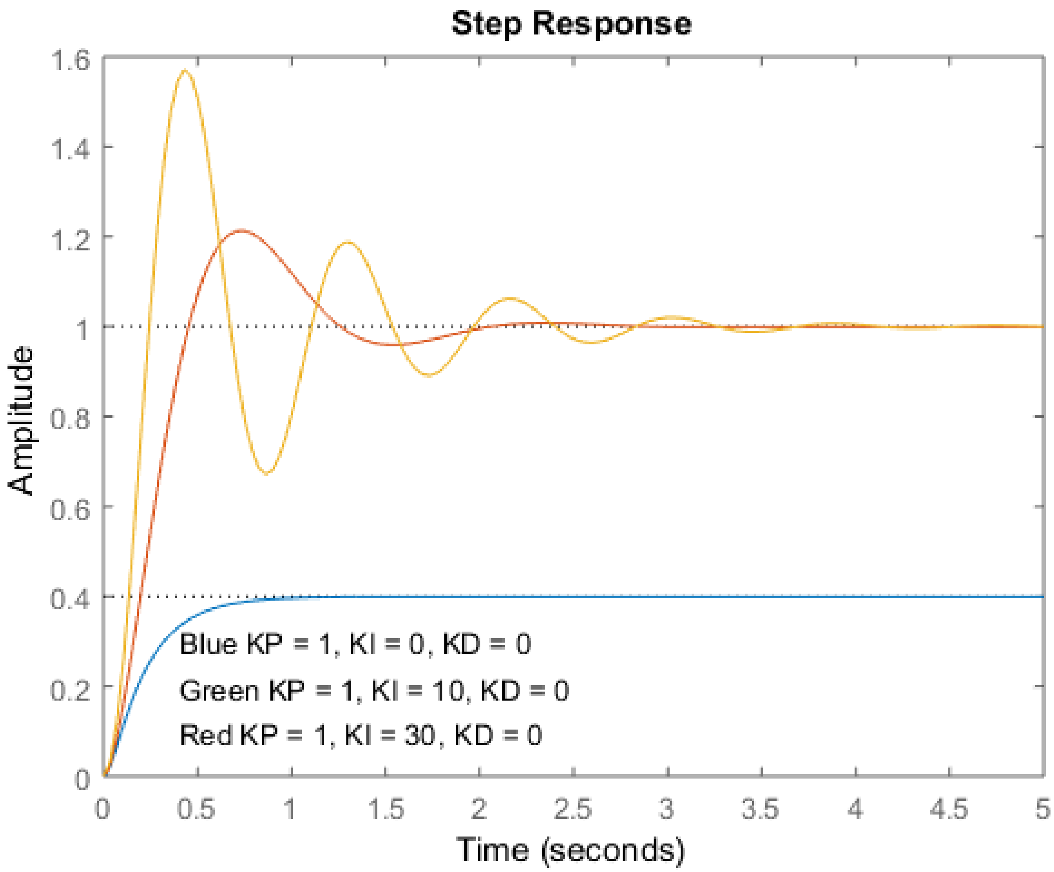

Figure 5: Varying KI System Response

```
     RiseTime: 0.4545
 SettlingTime: 0.8270
  SettlingMin: 0.3606
  SettlingMax: 0.3997
    Overshoot: 0
   Undershoot: 0
         Peak: 0.3997
     PeakTime: 1.4700
```

Figure 6: $KP = 1$, $KI = 0$, $KD = 0$

```
      RiseTime: 0.3201
  SettlingTime: 1.8350
   SettlingMin: 0.9166
   SettlingMax: 1.2130
     Overshoot: 21.3050
    Undershoot: 0
          Peak: 1.2130
      PeakTime: 0.7227
```

Figure 7: $KP = 1$, $KI = 10$, $KD = 0$

```
      RiseTime: 0.1623
  SettlingTime: 3.0579
   SettlingMin: 0.6712
   SettlingMax: 1.5716
     Overshoot: 57.1595
    Undershoot: 0
          Peak: 1.5716
      PeakTime: 0.4312
```

Figure 8: $KP = 1$, $KI = 30$, $KD = 0$

Third, values of $KP = 1$, $KI = 30$, $KD = 0$ were used for the controller. The KD was then changed to values of 2 and 10. The system responses for all three combinations are shown in Figure 9. The system characteristics of each combination are shown in Figure 10 through Figure 12. Notice that the increase in KD causes an decrease in overshoot and settling time.

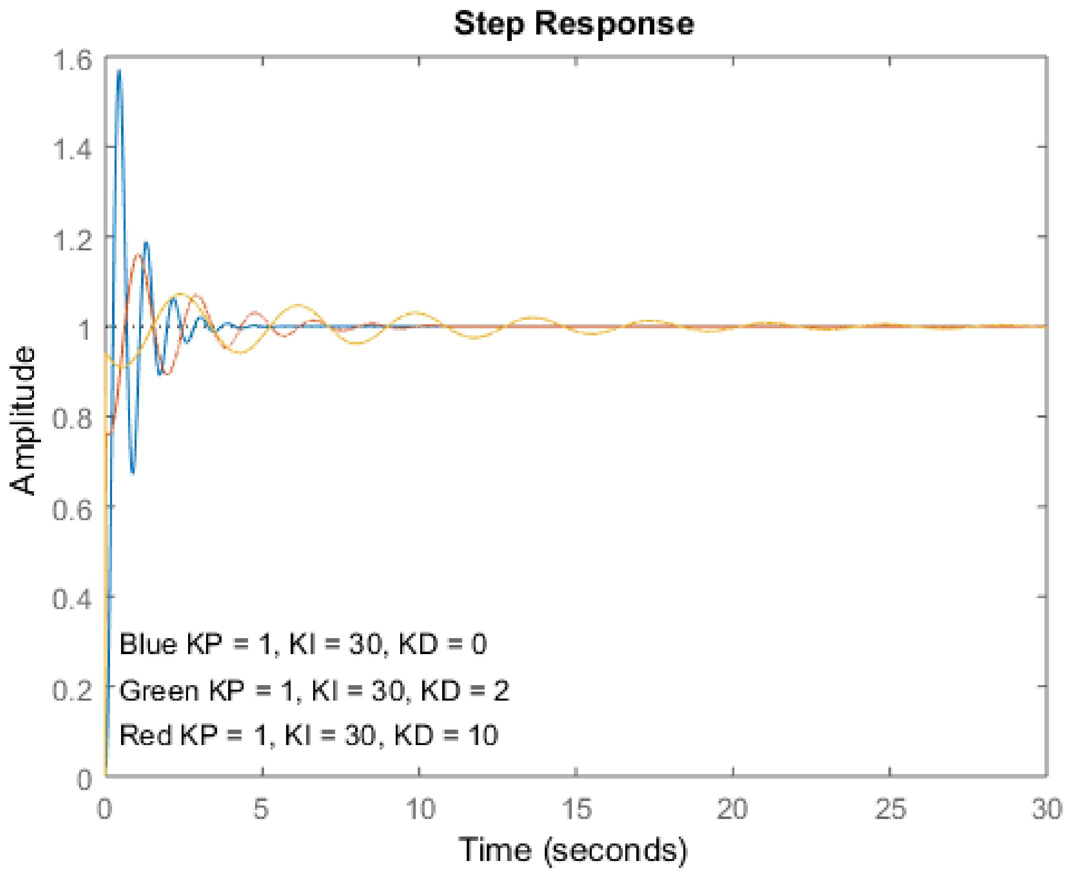

Figure 9: Varying KD System Response

```
        RiseTime: 0.1623
    SettlingTime: 3.0579
     SettlingMin: 0.6712
     SettlingMax: 1.5716
       Overshoot: 57.1595
      Undershoot: 0
            Peak: 1.5716
        PeakTime: 0.4312
```

Figure 10: $KP = 1$, $KI = 30$, $KD = 0$

```
        RiseTime: 0.4631
    SettlingTime: 5.7680
     SettlingMin: 0.8937
     SettlingMax: 1.1598
       Overshoot: 15.9815
      Undershoot: 0
            Peak: 1.1598
        PeakTime: 1.0393
```

Figure 11: $KP = 1$, $KI = 30$, $KD = 2$

```
        RiseTime: 0.0056
    SettlingTime: 12.1255
     SettlingMin: 0.9038
     SettlingMax: 1.0724
       Overshoot: 7.2355
      Undershoot: 0
            Peak: 1.0724
        PeakTime: 2.3944
```

Figure 12: $KP = 1$, $KI = 30$, $KD = 10$

Fourth, values of $KP = 1$, $KI = 0$, $KD = 0$ were used for the controller. The KI was then changed to a value of 30, and then the KD was changed to a value of 10. This combination of gains allows us to compare the effects of adding each component additionally to the controller. The system responses for all three combinations are shown in Figure 13. The system characteristics of each combination are shown in Figure 14 through Figure 16. Notice that the addition of integral control raises the overshoot and settling time, which is then decreased by adding a derivative component to the controller.

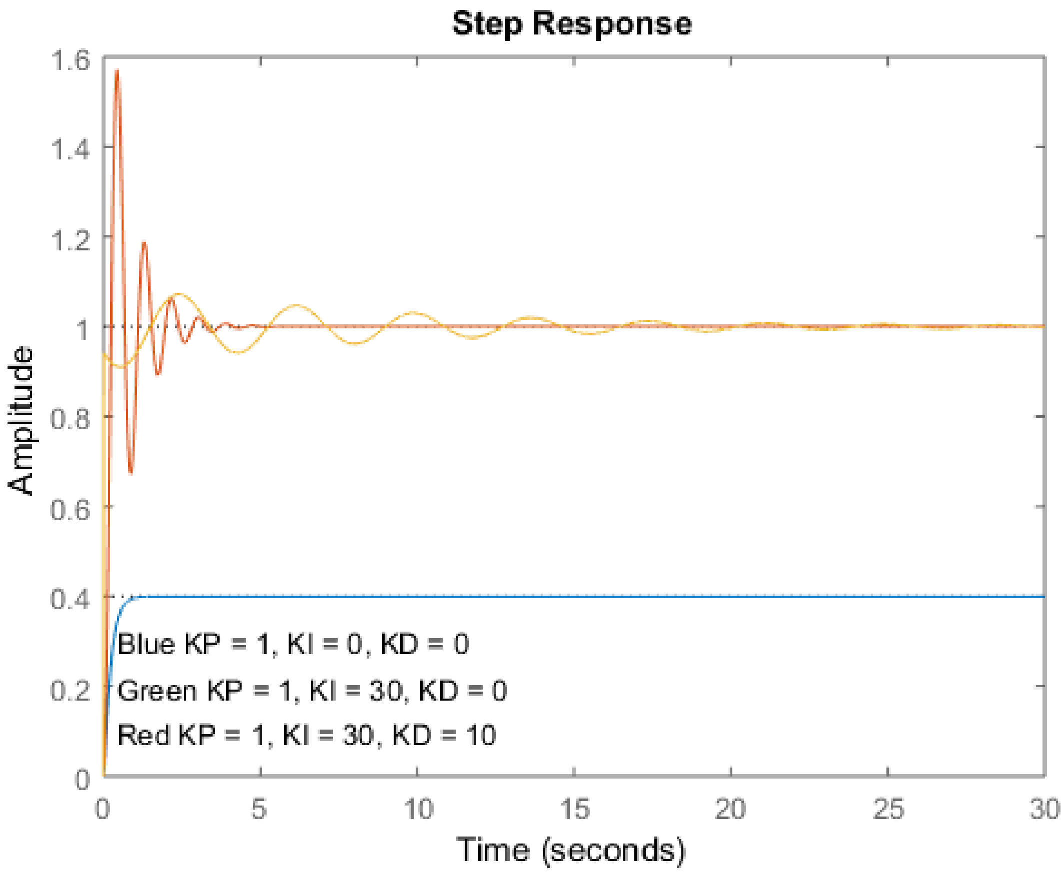

Figure 13: Sequential Addition of Components to Controller System Response

```
       RiseTime: 0.4545
   SettlingTime: 0.8270
    SettlingMin: 0.3606
    SettlingMax: 0.3997
      Overshoot: 0
     Undershoot: 0
           Peak: 0.3997
       PeakTime: 1.4700
```

Figure 14: $KP = 1$, $KI = 30$, $KD = 0$

RiseTime:	0.1623
SettlingTime:	3.0579
SettlingMin:	0.6712
SettlingMax:	1.5716
Overshoot:	57.1595
Undershoot:	0
Peak:	1.5716
PeakTime:	0.4312

Figure 15: $KP = 1$, $KI = 30$, $KD = 2$

RiseTime:	0.0056
SettlingTime:	12.1255
SettlingMin:	0.9038
SettlingMax:	1.0724
Overshoot:	7.2355
Undershoot:	0
Peak:	1.0724
PeakTime:	2.3944

Figure 16: $KP = 1$, $KI = 30$, $KD = 10$

Conclusion

The exercises conducted in this lab reinforce the theory learned in the classroom. It is shown that systems can be controlled using a PID controller, which is a tunable feedback controller which accounts for present, past, and future error states of the system. PID controllers are used widely in industrial applications, and this experience of adjusting a PID controller's gains and observing the effects on the controller is extremely useful to engineering students.