Alexandria University
Faculty of Engineering
Division of Communications & Electronics

EE 392 :Control Systems & Their Components

Lab 1 : Cruise Control using PID Controllers

Introduction

Automatic **cruise control** is an excellent example of a feedback control system found in many modern vehicles. The purpose of the cruise control system is to maintain a constant vehicle speed despite external **disturbances**, such as changes in wind or road grade. This is accomplished by measuring the vehicle speed, comparing it to the desired or **reference** speed, and automatically adjusting the throttle according to a **control law**.

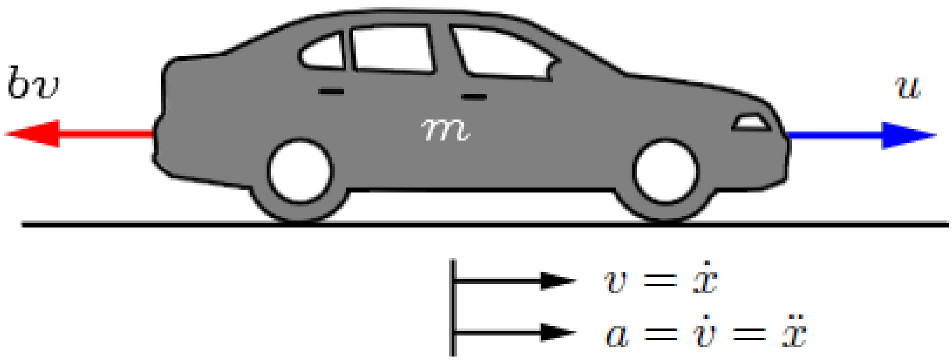

Figure 1: Free Body Diagram for a Vehicle

In this Lab, we consider a simple model of the vehicle dynamics, shown in the free-body diagram (FBD) above. The vehicle, of mass m, is acted on by a control force, (u). The force (u) represents the force generated at the road/tire interface. For this simplified model we will assume that we can control this force directly and will neglect the dynamics of the powertrain, tires, etc., that go into generating the force. The resistive forces, (bv), due to rolling resistance and wind drag, are assumed to vary linearly with the vehicle velocity, (v), and act in the direction opposite the vehicle's motion.

Physical Model

The physical model of the system flows from applying Newton's first Law in the X-direction. The system equation becomes:

$$\sum F(t) = ma(t)$$
$$u(t) - bv(t) = m\, \dot{v}(t)$$
$$m\, \dot{v}(t) + bv(t) = u(t) \tag{1}$$

where:

m = mass of the car
b = damping coefficient
$v(t)$ = car velocity at time t

The following equations are in time domain. Using Laplace transform on the system model, we arrive at the following equations:

$$m\ .\ s\ V(s) + b.V(s) = U(s)$$

and the transfer function is therefore:

$$\frac{V(s)}{U(s)} = \frac{1}{m\ s + b} \qquad \left[\frac{m/s}{N}\right] \tag{2}$$

Note: Typically Modelling of control systems is done in the Laplace Domain, therefore equation (2) would be of major importance in our lab procedure.

PID Controllers

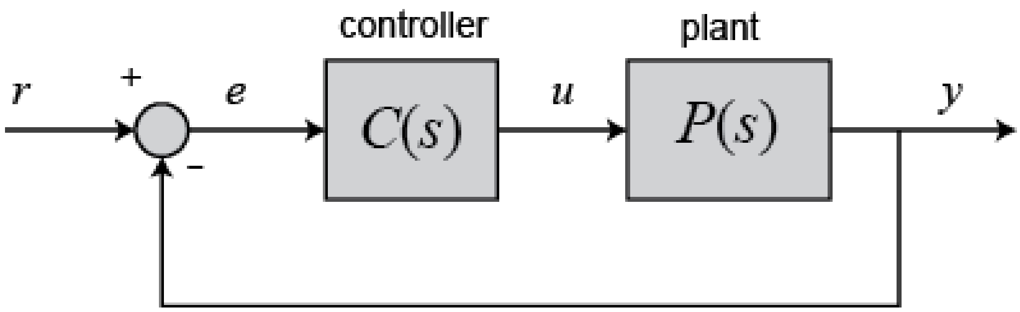

Figure 2: Feedback Block for PID Controller

Structures involving PID Controllers are simple yet versatile feeback control structures. PID is short for *Proportional-Integral-Derivative* controller. As the name describes,PID controllers perform their jobs by scaling the signal, its derivative and integral.

If we consider a unity feedback system as shown in the Figure 2. The system consists of the System to be controlled (The Plant $P(s)$) and the Controller $C(s)$ and a negative unity feedback. The desired value for the output y is input to the system as r. The output of the PID controller, equal to the control input to the plant, in the time-domain is as follows:

$$u(t) = K_p\, e(t) \;+\; K_i \int e(t) \;+\; K_d\, \frac{de(t)}{dt} \tag{3}$$

This control signal (u) is sent to the plant, and the new output (y) is obtained. The new output (y) is then fed back and compared to the reference to find the new error signal (e). The controller takes this new error signal and computes its derivative and its integral again, and so on.

The transfer function of a PID controller is found by taking the Laplace transform of the above equation to obtain:

$$\frac{U(s)}{E(s)} = K_p \;+\; K_d\, s \;+\; \frac{K_i}{s} = \frac{s^2\, K_d \;+\; K_p\, s \;+\; K_i}{s} \tag{4}$$

A proportional controller (K_p) will have the effect of reducing the rise time and will reduce but never eliminate the steady-state error. An integral control (K_i) will have the effect of eliminating the steady-state error for a constant or step input, but it may make the transient response slower. A derivative control (K_d) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response.

The effects of each of controller parameters K_p, K_i and K_d on a closed-loop system are summarized in the table below:

	RISE TIME	**OVERSHOOT**	**SETTLING TIME**	**Steady ERROR**
K_p	Decrease	Increase	Small Change	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small Change	Decrease	Decrease	No Change

Note that these correlations may not be exactly accurate, because K_p, K_i, and K_d are dependent on each other. In fact, changing one of these variables can change the effect of the other two. For this reason, the table should only be used as a reference when you are determining the values for K_p, K_i and K_d.

Lab Requirement

During the Lab period, you are required to:

1. Model the Car cruise system shown in Figure 1 and Equation (1) using MATLAB & SimuLink. The parameters for the system are as follows:
    - (m) vehicle mass = 1000 kg
    - (b) damping coefficient = 50 N.s/m
2. Model the PID controlled feedback structure using MATLAB & SimuLink.
3. Generate step response for the system when the controller has the following parameters:
    - (r) reference speed = 10 m/s
    - $(K_p) = 800$
    - $(K_i) = 40$
    - $(K_d) = 2$
4. Tweak the PID parameters to get the following performance parameters in the step response:
    - Rise time $<$ 5 sec
    - Overshoot $<$ 10%
    - Steady-state error $<$ 2%

Useful Matlab Hints

Useful Matlab functions : `tf, feedback, step`