Hands-on Lab 6

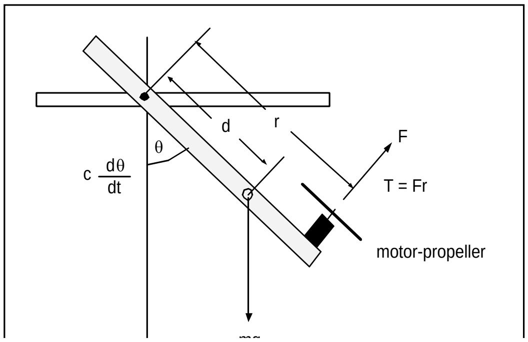
PID Control of a Damped Compound Pendulum

In Lab 1, the stated final course objective was "position regulation using *computer-controlled* state feedback". Looking back, one reached today's lab as follows:

Lab	Title	Lessons Learned
1	NI-DAQ Basics 1	Software tools: LabVIEW Basics
2	NI-DAQ Basics 2	Hardware tools: Data acquisition, aliasing
3	System Identification	Sensors: Encoders and 2nd order systems
4	Simulink Primer	Simulation: Computer tools for controller design
5	Designing Controllers	Pole placement and PID (tuning for performance)
6	**Real-world control**	**Implementing design in Real-World system**

Lab 6 is the culmination of all this effort and PID control will be applied so that the pendulum swings to the desired position angle with desired overshoot and desired settling time. One will see the tradeoffs between different gain settings and the stability or instability that results.

Concept 1: Open-loop Step Response

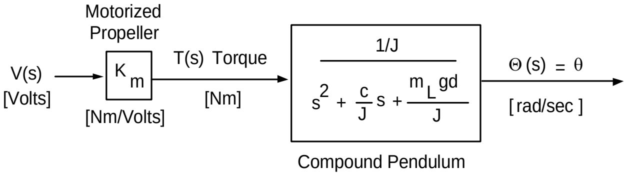


L	Bar length	0.495	m
d	Pivot to CG distance	0.023	m
m_L	Mass of pendulum	0.43	kg
J	Moment of Inertia	0.0090	kgm^2
c	Viscous damping	0.00035	Nms/rad

Equation of Motion

$$\boxed{J\ddot{\theta} + c\dot{\theta} + m_L gd\sin\theta = T}$$

Recall that the above system has a block diagram given by:

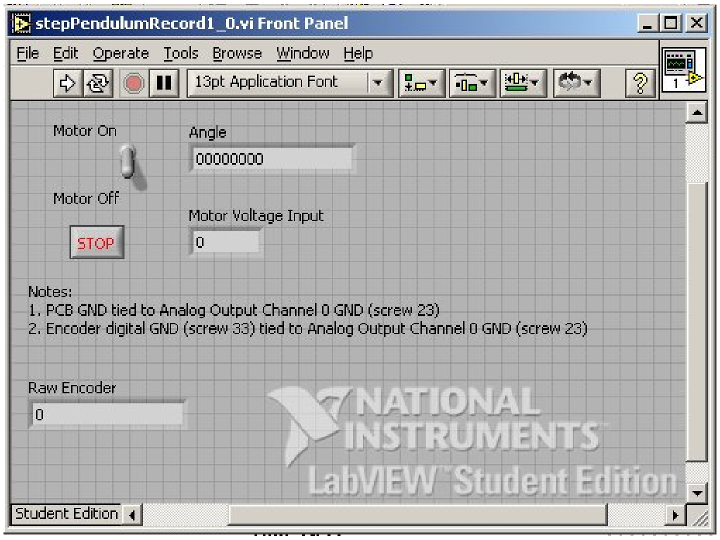


The element K_m relates voltage into the motor V to torque T applied to the pendulum. Given a step input voltage, the pendulum will eventually reach a steady-state angle θ_{ss}. This point is called dynamic equilibrium and dictates that:

$$K_m = \frac{m_L gd\sin\theta_{ss}}{V} \tag{1}$$

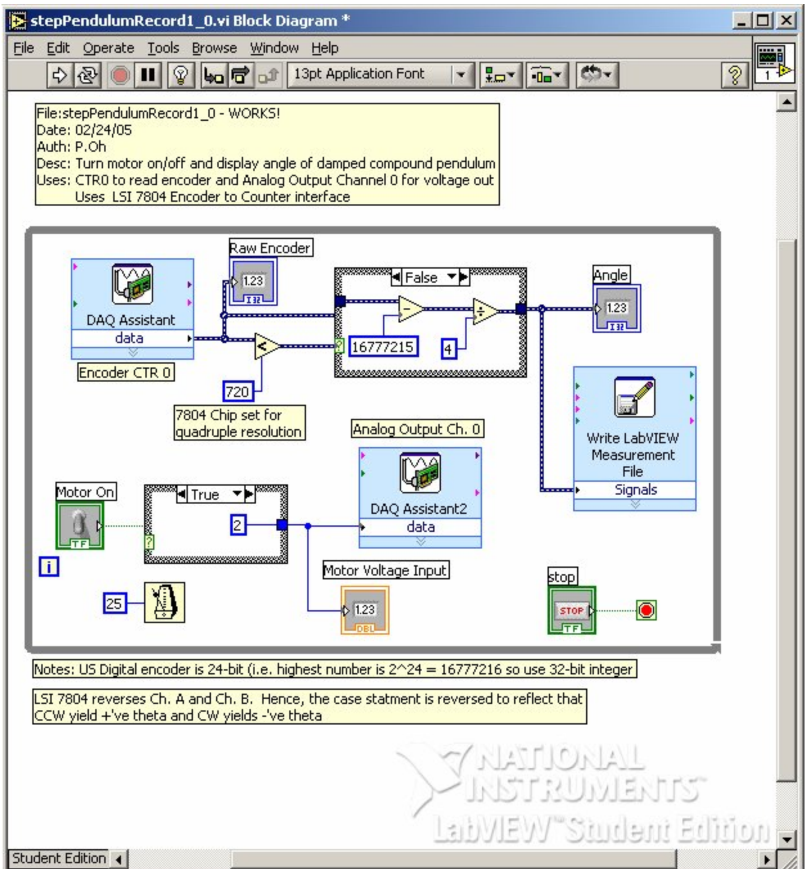
As such, one will create a LabVIEW program to apply a voltage to the motor and display the angle position. When the motor stops oscillating, one can calculate K_m using equation (1).

Step 1: Create the following LabVIEW panel and block diagram



Notes:
1. PCB GND tied to Analog Output Channel 0 GND (screw 23)
2. Encoder digital GND (screw 33) tied to Analog Output Channel 0 GND (screw 23)

Step 2: The block diagram for the above is given by



File:stepPendulumRecord1_0 - WORKS!
Date: 02/24/05
Auth: P.Oh
Desc: Turn motor on/off and display angle of damped compound pendulum
Uses: CTR0 to read encoder and Analog Output Channel 0 for voltage out
Uses LSI 7804 Encoder to Counter interface

7804 Chip set for quadruple resolution

Notes: US Digital encoder is 24-bit (i.e. highest number is 2^24 = 16777216 so use 32-bit integer

LSI 7804 reverses Ch. A and Ch. B. Hence, the case statment is reversed to reflect that CCW yield +'ve theta and CW yields -'ve theta

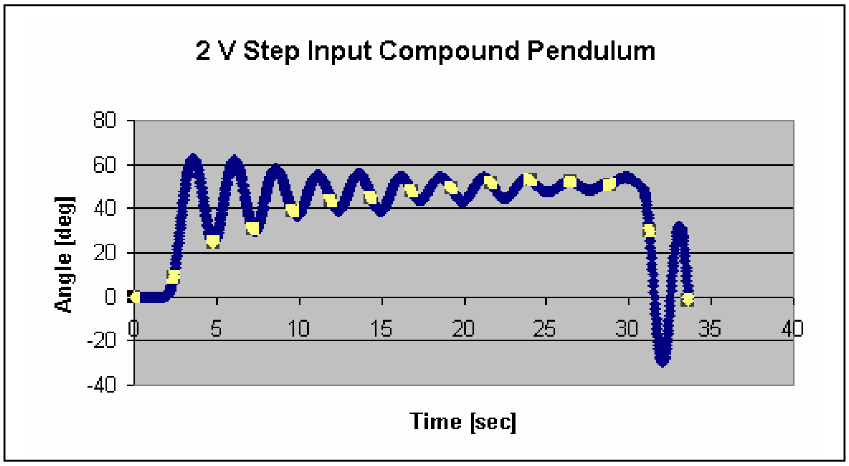
Step 3: Motor, power op-amp and encoder wire up

Turn off Power Supply before making the following connections!

Part 1	Part 2
Motor +'ve	PCB +Motor pin
Move –'ve	PCB -Motor pin
Power Supply +12 Volts	PCB PWR pin
Power Supply Ground	PCB GND
Encoder 5-pin Female	PCB 5-pin Male header
PCB U/D pin	LabVIEW pin 30 (Counter 0 Up/Down)
PCB SRC pin	LabVIEW pin 47 (Counter 0 Source)
PCB GND pin	LabVIEW pin 33 (Digital Ground)
PCB +5V pin	LabVIEW pin 34 (+5V)
PCB INP pin	LabVIEW pin 20 (A0)
Power Supply Ground	LabVIEW pin 23 (A0 Ground)

Step 4: Turn on the Power Supply and Execute your VI (**`stepPendulumRecord1_0`**)

The motor should turn and eventually stop oscillating about 15 seconds. Record the angle displayed on your VI. Use the acquired data to plot in Excel the following:



Exercise 1

1-1 Using Equation (1), calculate the constant K_m. What is your steady state angle for a 2 Volt step input?

Concept 2: Simulink Simulation

Step 1: Using your constant K_m create the Simulink block diagram in **Figure 1**

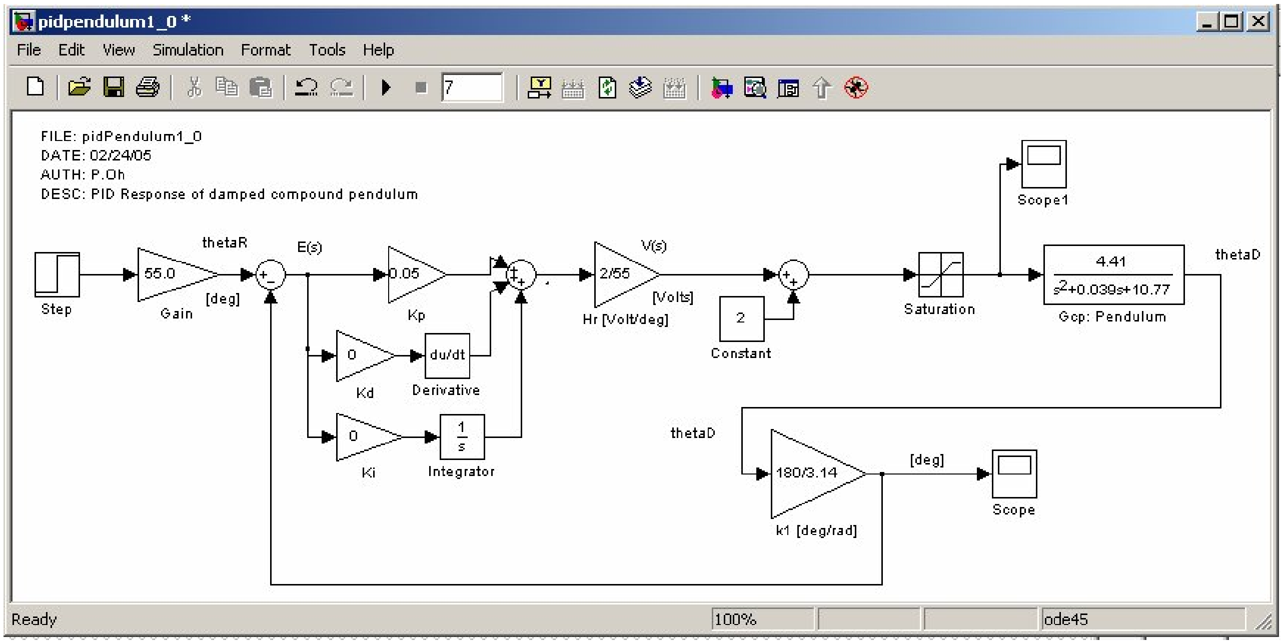

FILE: pidPendulum1_0
DATE: 02/24/05
AUTH: P.Oh
DESC: PID Response of damped compound pendulum

Figure 1: Simulink block diagram for a PID controller. Note: incorporate K_m into the transfer function. Also, the set-point angle should correspond to the steady-state angle calculated in **Exercise 1-1.**

Step 2: Run the simulation with the gains $K_p = 0.25$, $K_I = 0$, $K_D = 0.5$ to get a response similar to Figure 2

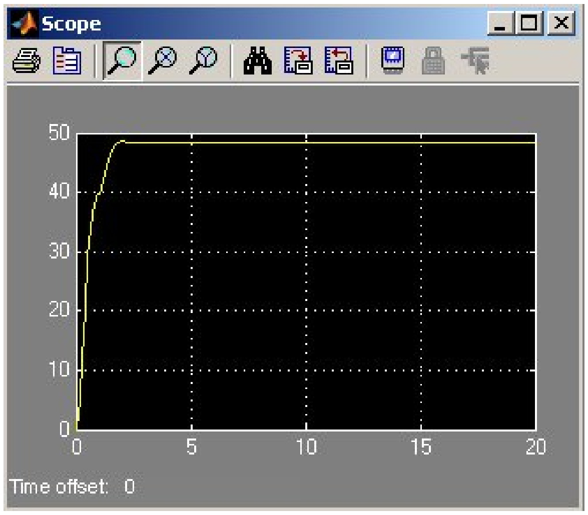
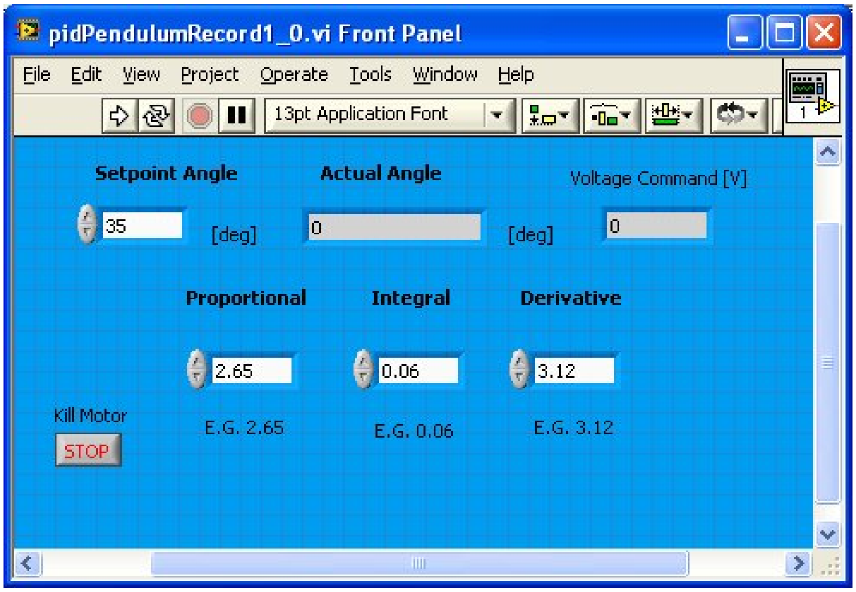


Figure 2: Scope output for PID gains (0.25, 0, 0.5)

Step 3: PID Implementation in LabVIEW. Create the following front panel



Setpoint Angle 35 [deg]

Actual Angle 0 [deg]

Voltage Command [V] 0

Proportional 2.65

E.G. 2.65

Integral 0.06

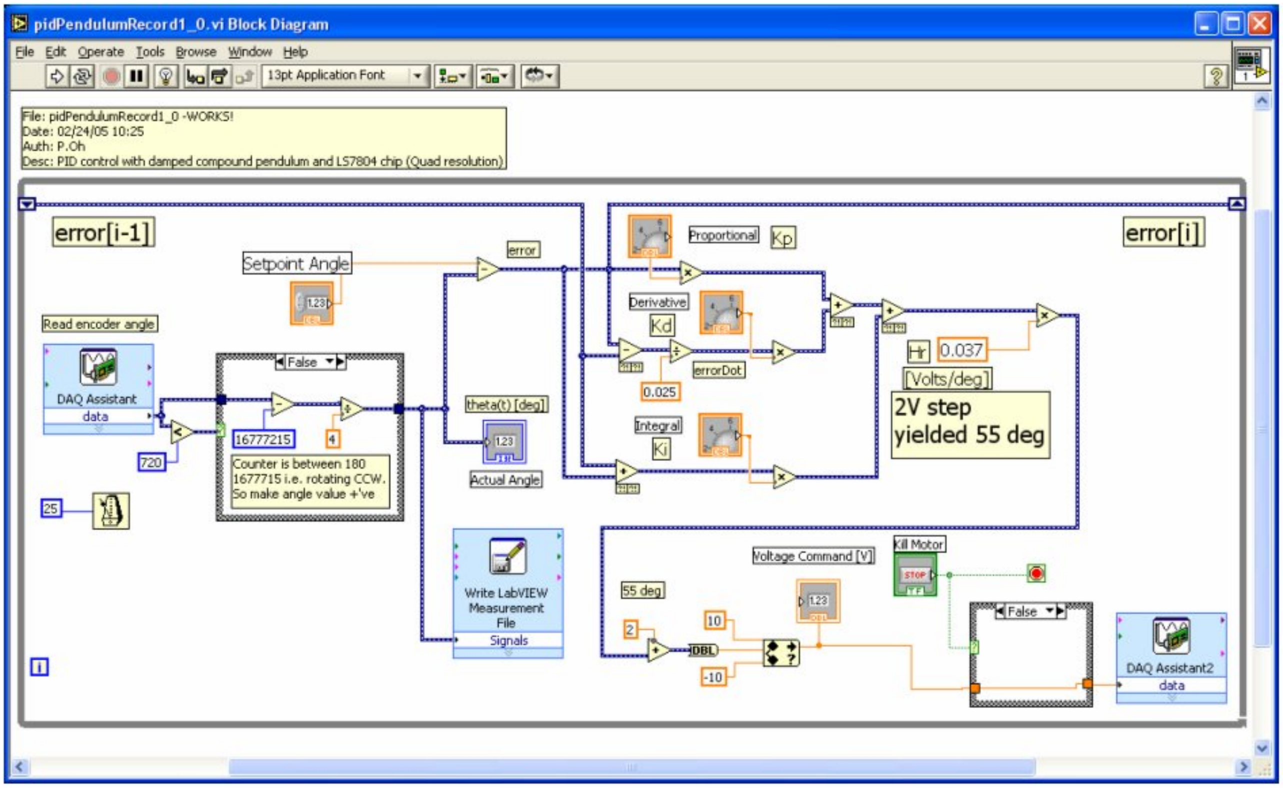
E.G. 0.06

Derivative 3.12

E.G. 3.12

Figure 3: PID front panel (`pidPendulumRecord1_0`)

Step 4: The associated block diagram is given as



File: pidPendulumRecord1_0 -WORKS!
Date: 02/24/05 10:25
Auth: P.Oh
Desc: PID control with damped compound pendulum and LS7804 chip (Quad resolution)

Counter is between 180 1677715 i.e. rotating CCW. So make angle value +'ve

2V step yielded 55 deg

Figure 4: Block diagram for PID controller. Note: "`In Range and Coerce`" control (`All functions – Comparison`) is used to limit output voltages between -10 to +10 Volts. The input into this control is type cast to be a `double` (`All functions – Numeric – Conversion – To Double Precision Float`)

Step 5: Execute your VI using the gains you used in the Simulink simulation in Step 2 by turning the virtual dials: $K_p = 0.25$, $K_I = 0$, $K_D = 0.5$. Plot out the data acquired. It should look like **Figure 5**.

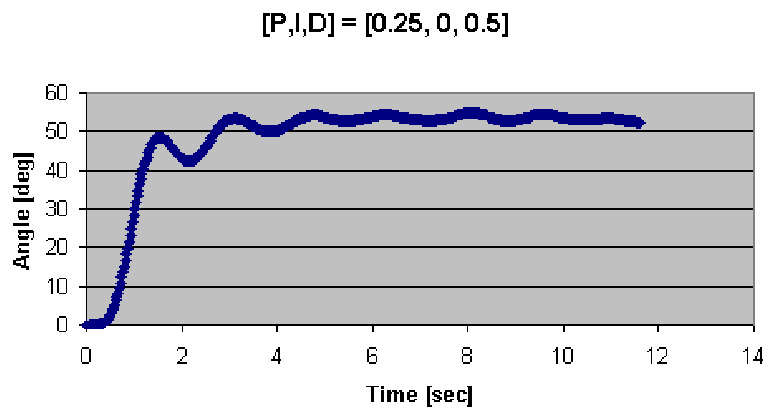
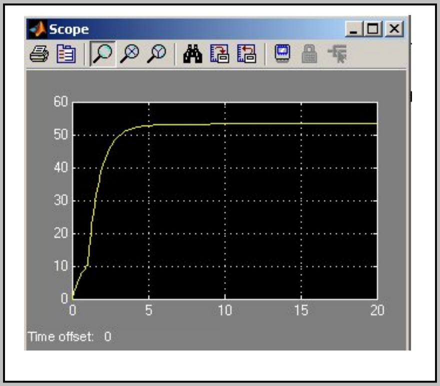


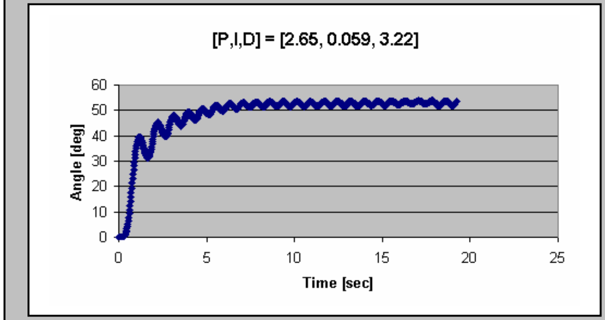
Figure 5: Excel plot with gains set in Step 5. Note how it resembles the Simulink response in **Figure 2**.

Exercise 2

2-1 In Simulink capture the scope figure for gains $(K_p, K_I, K_D) = (2.65, 0.059, 3.22)$

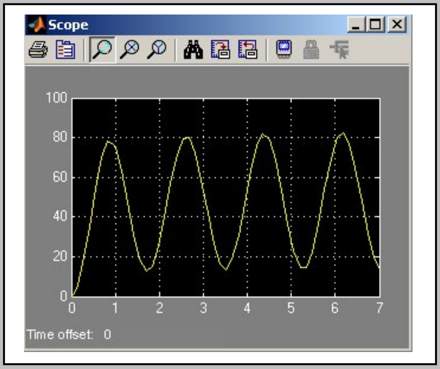
2-2 In LabVIEW plot the Excel plot for the gains in 2-1

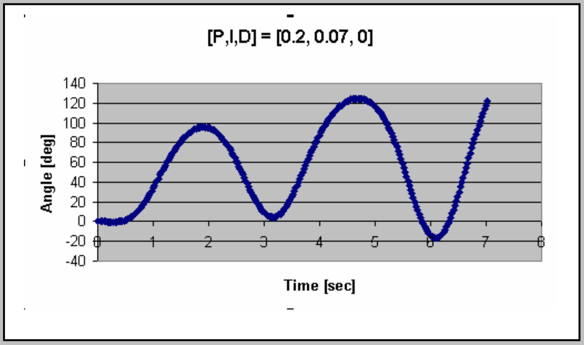




2-3 In Simulink capture the scope figure for gains $(K_p, K_I, K_D) = (0.2, 0.07, 0)$

2-4 In LabVIEW plot the Excel plot for the gains in 2-3. Please take care not to damage the pendulum if the system goes unstable.





2-5 Sketch a diagram of the experimental setup – this will be needed for your Final Lab Report.

2-6 Move the pivot point to a position a few notches away from the pendulum's center-of-mass. Capture the data with gains $(K_p, K_I, K_D) = (2.65, 0.059, 3.22)$. Compare the plot with the one acquired in Exercise 2-2.

2-7 Adjust the VI knobs to get a better steady-state response. Plot the acquired data. What is the rise time, overshoot (if any) and settling angle?