ECEN315 LABORATORY REPORT ONE

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1 Introduction

This project has the goal of creating a system for controlling a pendulum arm driven by a propeller. This necessitates the modelling of system, breaking it sub-blocks/subsystems and evaluating these models. The work outlined in this report

2 Background

In this section you should give a brief background, e.g. control theory and motors.

3 Methodology and Results

In this section you will explain how to solve the problem, that is, how you performed the project. At this early stage you need to be both clear about what you did and why you did it. You will also explain how you evaluated your solution once you have built it. The method of evaluation will be specific to the tasks.

3.1 DC Motor and Propeller

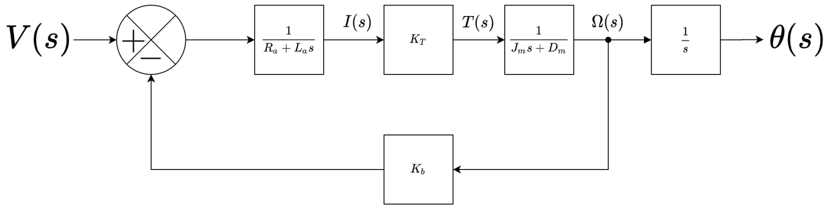


Figure 1: Block Diagram of DC Motor+Propeller System

$$
\begin{aligned}
\frac{\Omega(s)}{V(s)} &= \frac{\frac{K_t}{(R_a+L_a s)(D_m+J_m s)}}{1+\frac{K_t K_b}{(R_a+L_a s)(D_m+J_m s)}} \\
&= \frac{K_t}{(R_a + L_a s)(D_m + J_m s) + K_t K_b} \\
&= \frac{K_t}{L_a J_m s^2 + (R_a J_m + L_a D_m)s + R_a D_m + K_t K_b} \\
&= \frac{\frac{K_t}{L_a J_m}}{s^2 + \frac{R_a J_m + L_a D_m}{L_a J_a} s + \frac{R_a D_m + K_t K_b}{L_a J_m}}
\end{aligned}
$$

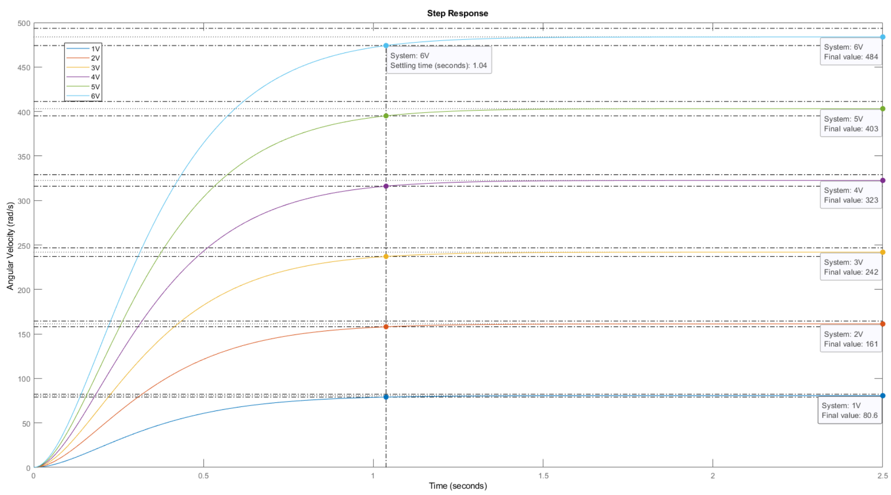


Figure 2: Step response

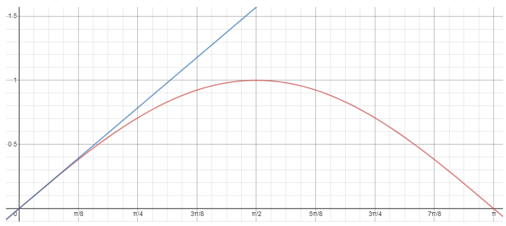
```
Steady state gain for V = 1: 80.631551
Steady state gain for V = 2: 80.631551
Steady state gain for V = 3: 80.631551
Steady state gain for V = 4: 80.631551
Steady state gain for V = 5: 80.631551
Steady state gain for V = 6: 80.631551
```

3.2 Pendulum

For the driven pendulum, the torque applied to the pendulum must balance with the existing torques, ie from gravity, damping and the arms moment of inertia. Before the DE is derived, I needed to approximate the torque applied via gravity:

$$\tau_{gravity} = mgd{\cdot}sin(\theta) = mgd{\cdot}\theta$$

This approximation works for small angles, but quickly diverges in accuracy for $\theta \geq \pi/8 \rightarrow \pi/4$



3.2.1 Differential Equation and Transfer Function

$$\begin{aligned}
\tau(t) &= J_p \frac{d^2\Theta}{dt^2} + c\frac{d\Theta}{dt} + mgd\Theta \\
T(s) &= J_p s^2\Theta(s) + cs\Theta(s) + mgd\Theta(s) \\
\frac{\Theta(s)}{T(s)} &= \frac{1}{J_p s^2 + cs + mgd} \\
&= \frac{\frac{1}{J_p}}{s^2 + \frac{c}{J_p}s + \frac{mgd}{J_p}}
\end{aligned}$$

3.2.2 Calculating Damping and Inertia

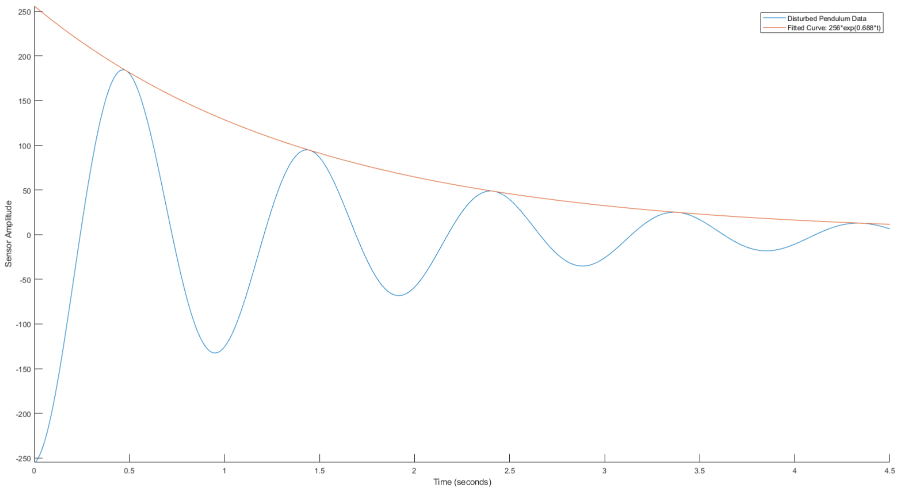


Figure 3:

Full Open Loop TF

$$
\begin{aligned}
\frac{\Theta(s)}{V(s)} &= \frac{\frac{K_t}{L_a J_m}}{s^2 + \frac{R_a J_m + L_a D_m}{L_a J_m} s + \frac{R_a D_m + K_t K_b}{L_a J_m}} \cdot K_p \cdot r \cdot \frac{\frac{1}{J_p}}{s^2 + \frac{c}{J_p} s + \frac{mgd}{J_p}} \\
&= \frac{\frac{K_t K_p r}{J_p L_a J_m}}{(s^2 + \frac{c}{J_p} s + \frac{mgd}{J_p})(s^2 + \frac{R_a J_m + L_a D_m}{L_a J_m} s + \frac{R_a D_m + K_t K_b}{L_a J_m})}
\end{aligned}
$$

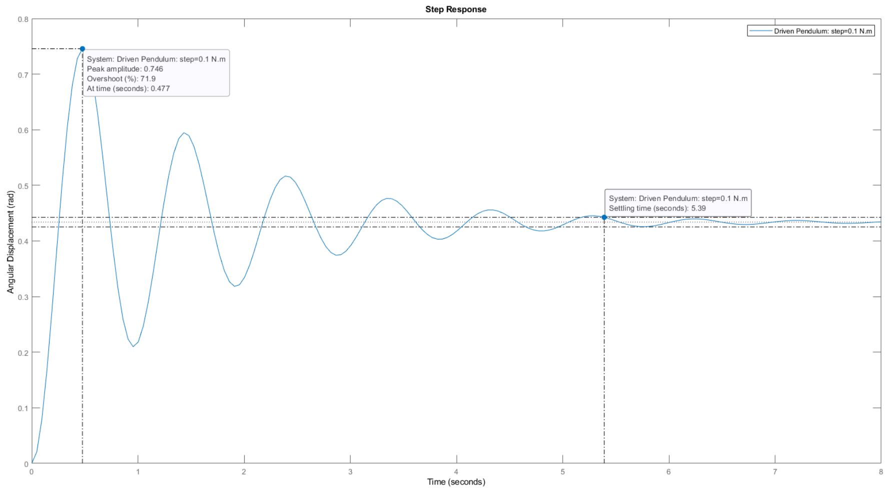


Figure 4:

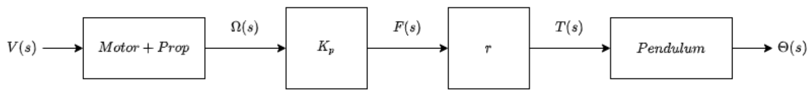


Figure 5: Block Diagram of DC Motor+Propeller System

4 Discussion

Big picture considerations, e.g. is your model useful or not?

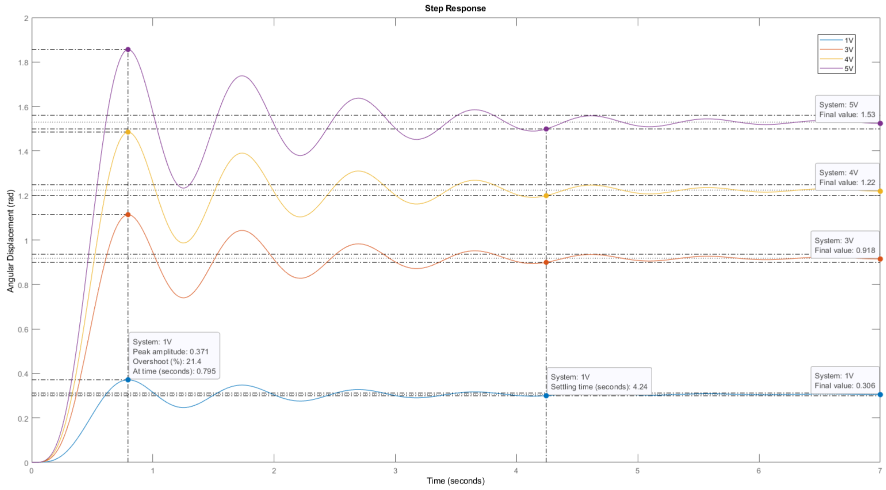


Figure 6:

5 Conclusions

6 Full MatLab Code

```
%% lab 2 Motor + Prop Sub-System
clear;
clc;

Ra = 6.3;
La = 0.797;
Kb = 0.0043;
Kt = Kb;
Dm = 0.00000553;
Jm = 0.00000241;

numerator = Kt/(Jm*La);
denom_a = 1;
denom_b = (Jm*Ra + Dm*La)/(Jm*La);
denom_c = (Ra*Dm + Kb*Kt) / (Jm*La);

motor_prop = tf(numerator, [denom_a denom_b denom_c])

figure;
hold on
for V = [1 2 3 4 5 6]
step(V*motor_prop)
ylabel("Angular Velocity (rad/s)")
ssg = (numerator/denom_c);
fprintf("Steady state gain for V = %d: %f\n",V, ssg);
end

%% import Data
opts = delimitedTextImportOptions("NumVariables", 2);

% Specify range and delimiter
opts.DataLines = [1, Inf];
opts.Delimiter = "\t";

% Specify column names and types
opts.VariableNames = ["t", "x"];
opts.VariableTypes = ["double", "double"];

% Specify file level properties
opts.ExtraColumnsRule = "ignore";
opts.EmptyLineRule = "read";

% Import the data
Data = readtable("Data.csv", opts);
CSV_t = Data.t;
CSV_x = Data.x;
clear opts

%% Fit decay curve
figure;
hold on
plot(CSV_t,CSV_x)
A = 256; %max sensor value
B = 0.688;
y = A*exp(-B*CSV_t);
plot(CSV_t,y)
```

```
ylim([-255 256])
ylabel("Sensor Amplitude")
xlabel("Time (seconds)")
hold off


%% Pendulum Sub-System
m = 0.168;
g = 9.8;
d = 0.14;

w = (2*pi)/(1.43-0.47);
Jp = (m*g*d)/(w^2 + B^2);
c = 2*Jp*B;

numerator = 1/Jp;
denominator = [1 c/Jp (m*g*d)/Jp];

pendulum = tf(numerator,denominator)
figure;
step(0.1*pendulum)
ylabel("Angular Displacement (rad)")
%% Combined Open loop system
Kp = 0.0053;
r = 0.165;

combined_sys = motor_prop .* Kp .* r .* pendulum

figure;
hold on
for V = [1 3 4 5]
step(V*combined_sys)
end
ylabel("Angular Displacement (rad)")
```

7 Lab Safety

Hazard	Cause	Probability	Severity	Mitigation
Lacerations from propeller	Touching propeller while in operation	Low	High	Keep human appendages a safe distance away from objects moving at a high speed.
Burning skin	Motor overheats because it is running for too long and someone's skin touches it. Soldering Iron	Moderate	Low	Do not run motors and equipment longer than necessary, and/or for longer than they are capable of running for. If it has been running for too long, turn it off and do not touch until it has cooled down.
Respiratory Problems	Inhaling soldering smoke	High	Moderate	Use fan
Eye-injury/Shrapnel	Plastic shards/other pieces thrown by spinning motor	Moderate	High	Wear eye protection, safety goggles, whenever in range of operating motor
Cutting skin	Standing on bare feet/bare skin coming into contact with sharp objects.	Low	Moderate	Wearing closed shoes at all times in lab
Broken bones and head injury	Tripping on equipment and falling over in a damaging way.	Low/moderate	High	Be aware of surroundings and avoid objects that could cause a person to become physically unstable.
Electric shock	Touching/Messing with the high current mains connection and Incorrect wiring of circuits and malfunctioning electrical devices.	Moderate	High	Double check wiring, keep higher power circuitry isolated, be informed/engaged with what is going on around you
Explosion injuries	Equipment overheats/malfunctions and explodes near humans.	Low	High	If a major malfunction of equipment is noticed, call campus health/111 and evacuate the building immediately.
Dehydration/General Nausea/Fatigue	Not leaving lab, not taking breaks, and/or not having a water bottle	High	Low	Consume adequate amounts of water and food, take breaks and leave the lab environment when needed.
Back Injury	Lifting heavy equipment	Moderate	High	When lifting heavy equipment, do this with sensible lifting processes (e.g. bend knees, 2nd person etc). Or roll it if it has wheels.