Control Challenges: Solutions

Iacopo Moles

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1 Introduction

1.1 What is this?

This is a collection of write ups on how to solve the various problems presented by Github user “Janismac”.

2 Block With Friction

Position Control with friction. Using Pole Placement + PD.

2.1 State Space representation

We can convert the set of ODE into a state space representation. The final bode plot of the block position is:

```
using DiscretePIDs, ControlSystems, Plots, LinearAlgebra

# System parameters
Ts = 0.02 # sampling time
Tf = 2.5; #final simulation time
g = 9.81 #gravity
α = 0.0 # slope
μ = 1.0 # friction coefficient
x_0 = -2.0 # starting position
dx_0 = 0.0 # starting velocity
τ = 20.0 # torque constant

# State Space Matrix
A = [0 1 0
    0 -μ 1
    0 0 -τ
]*1.0;
B = [0
    0
    τ]*1.0;
C = [1 0 0
    0 1 0]*1.0

sys = ss(A, B, C, 0)      # Continuous
```

```
bodeplot(tf(sys))
```

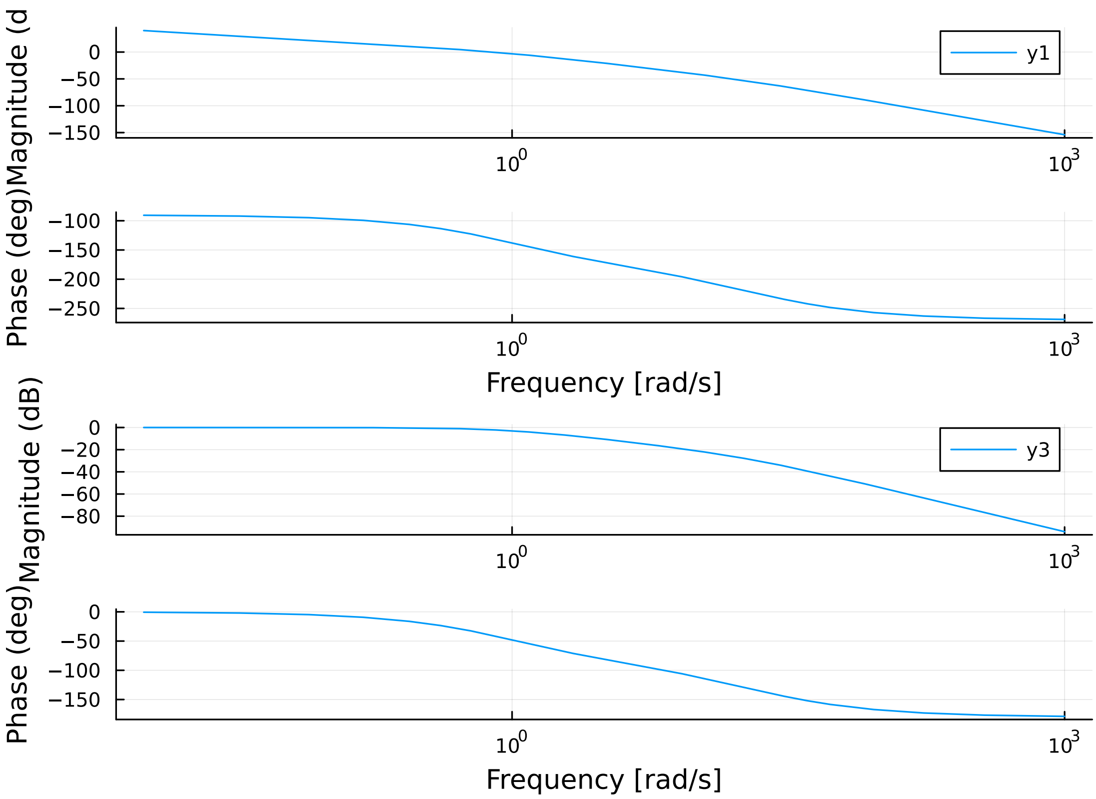


Figure 2.1: Starting Bode Plot

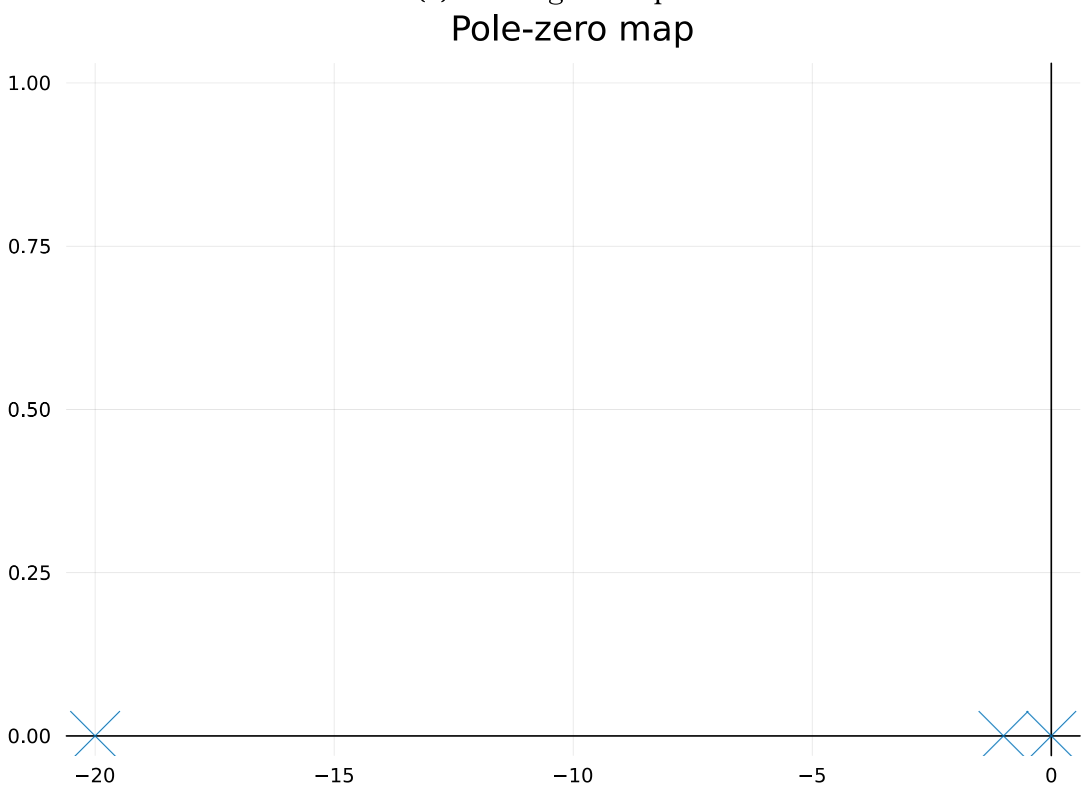
It has the shape we expect from a motor + friction. Slow pole for the mass + friction and a faster pole for the current & inductance.

Numerically they are:

```
display(eigvals(A)) # -20 , -1, 0
display(pzmap(tf(sys)))
```

```
3-element Vector{Float64}:
 -20.0
  -1.0
   0.0
```

(a) Starting PZ map



(b)

Figure 2.2

In Figure 2.2 we see that we start with all the pole in the left-half plane, which is good.

2.2 Pole Placement

We can design a controller with pole placement.

For some reason pole placement doesn't work for the observer, I use a Kalman Filter with random fast values.

```
display(observability(A, C)); #OK
display(controllability(A, B)); #OK
ϵ = 0.01;
pp = 15;
p = -2* [pp + ϵ , pp - ϵ , (pp / 4)];
L = real(place(sys, p, :c));

poles_obs = p*5.0
K = place(1.0*A',1.0*C', poles_obs)'
cont = observer_controller(sys, L, K; direct=false);
```

```
┌ Warning: Max iterations reached
└ @ ControlSystemsBase C:\Users\icpmoles\.julia\packages\ControlSystemsBase\IeuP
```

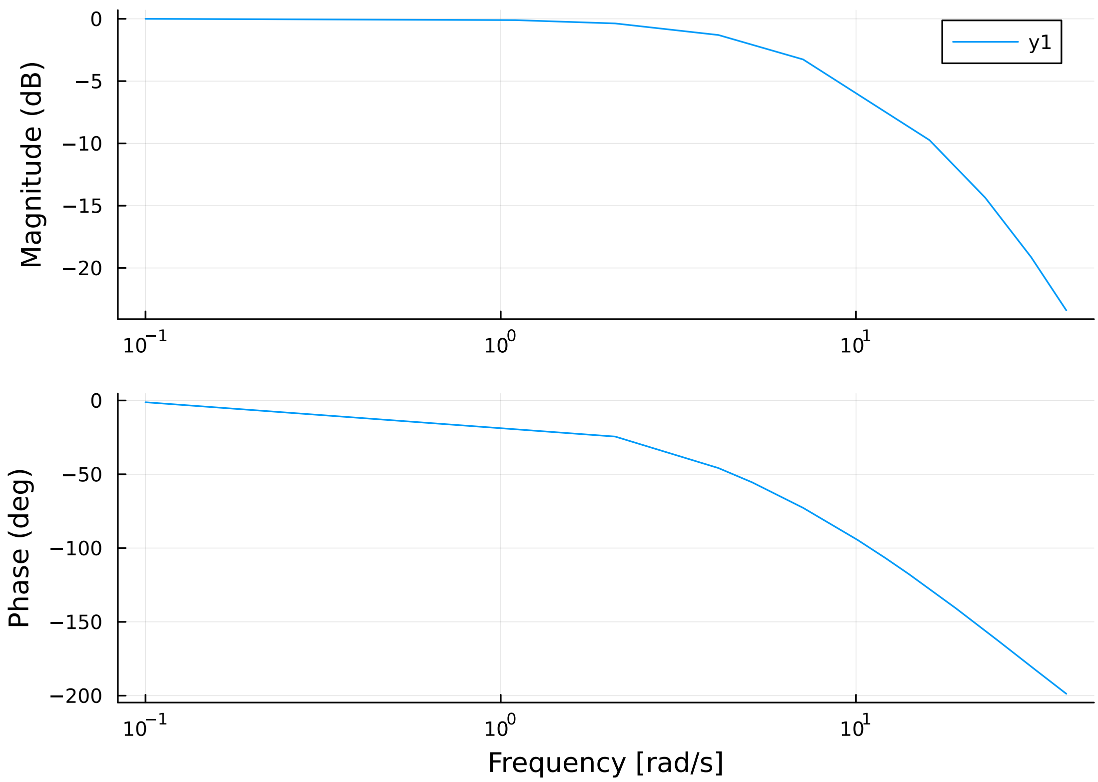
```
(isobservable = true, ranks = [3, 3, 3], sigma_min = [0.05255163155979671, 1.000000
```

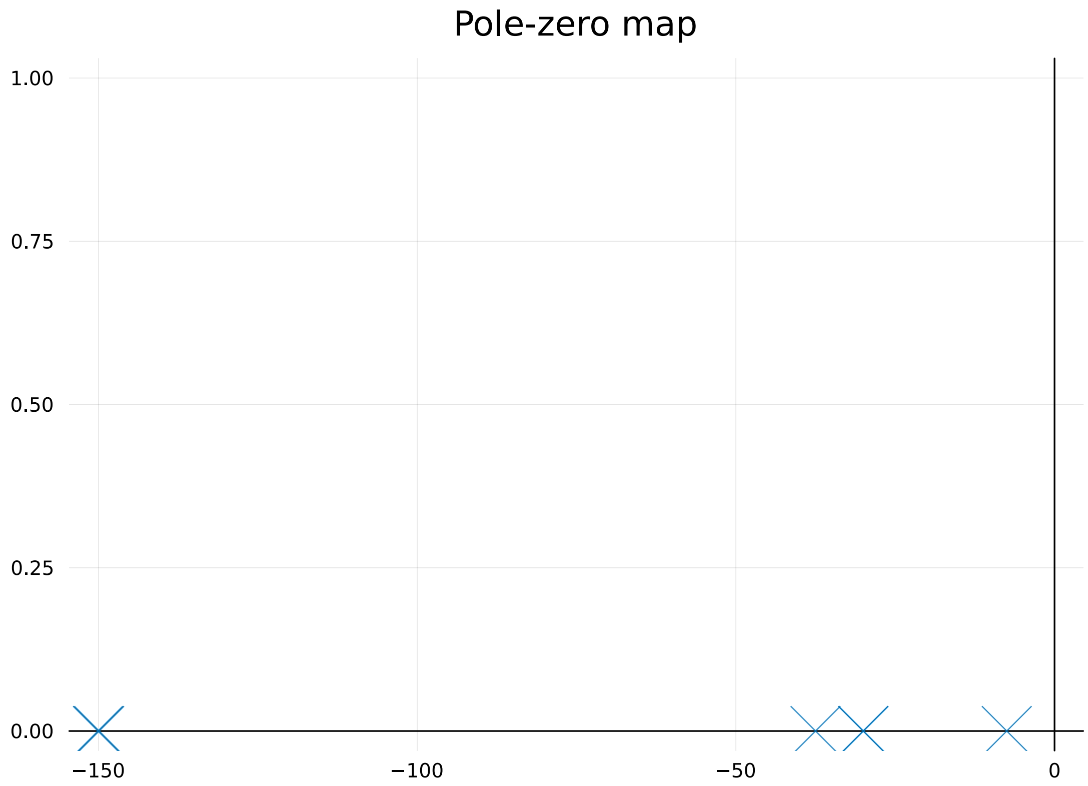
```
(iscontrollable = true, ranks = [3, 3, 3], sigma_min = [18.82217025796643, 0.724773
```

We can check the effect of the new controller on the loop

```
closedLoop = feedback(sys*cont)
print(poles(closedLoop));
setPlotScale("dB")
display(bodeplot(closedLoop[1, 1], 0.1:40))
display(pzmap(closedLoop))
```

```
ComplexF64[-150.09999999999997 + 0.0im, -149.89999999999995 + 0.0im, -
7.500000000000134 + 0.0im, -29.979999999868912 + 0.0im, -30.020000000130636 + 0.0i
37.50000000000044 + 0.0im]
```


0
−5
−10
−15
−20
Magnitude (dB)
y1
10^−1
10^0
10^1
0
−50
−100
−150
−200
Phase (deg)
10^−1
10^0
10^1
Frequency [rad/s]



We can compare this to the open-loop response in Figure 2.1. We can see that we achieve unitary gain throughout the whole low-frequency range.

We can convert the pole placement controller into the standard PD gain form.

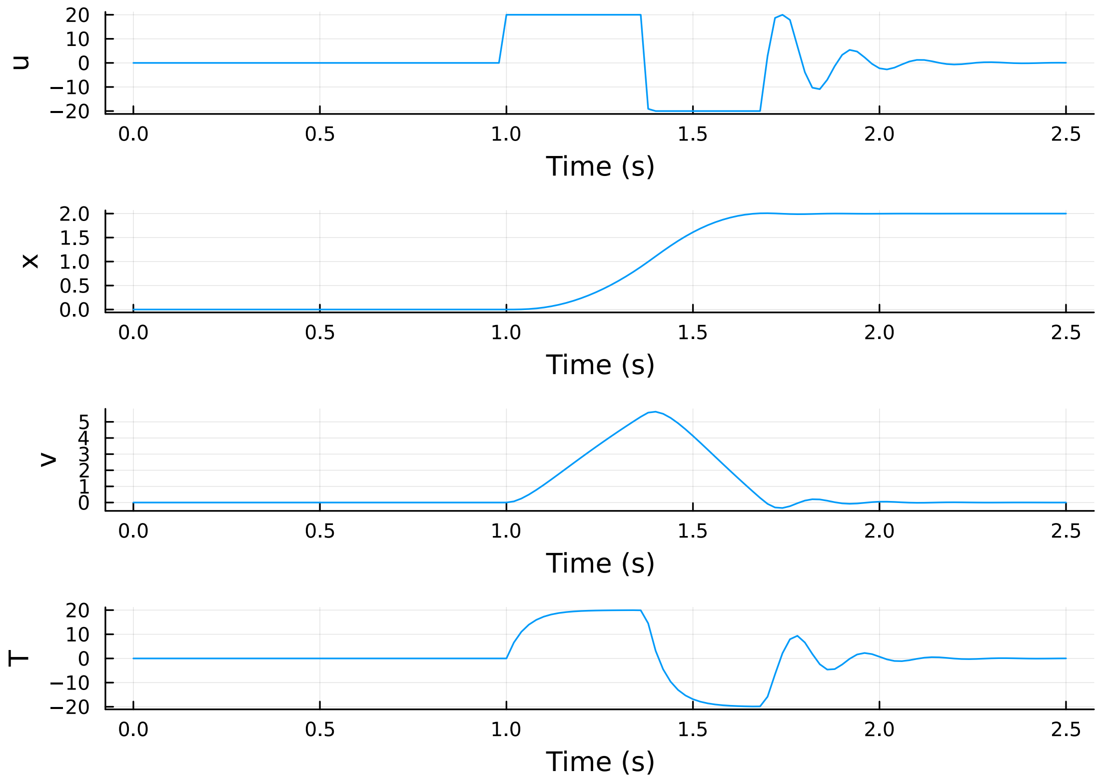
```
K = L[1];
Ti = 0;
Td = L[2] / L[1];
pid = DiscretePID(; K, Ts, Ti, Td);
```

2.3 Simulation

We can simulate this with a motor that only outputs the position:

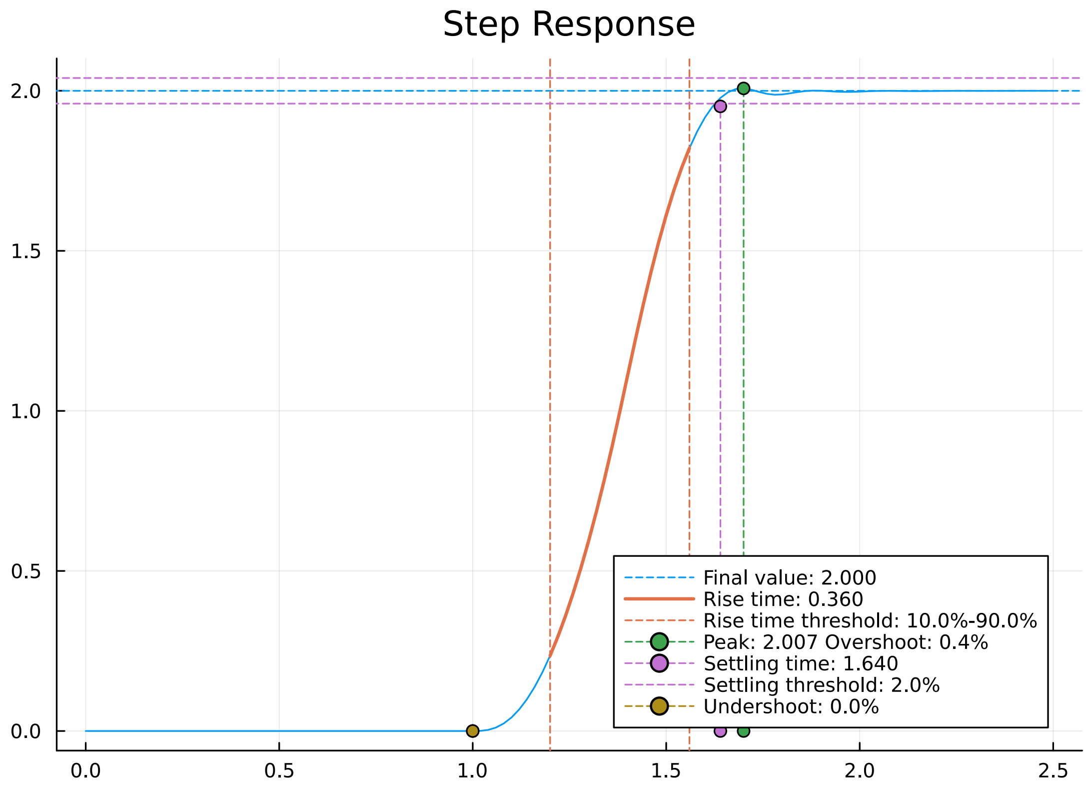
```
sysreal = ss(A, B, [1 0 0], 0)
ctrl = function (x, t)
    y = (sysreal.C*x)[] # measurement
    d = 0 * [1.0]        # disturbance
    r = 2 * (t >= 1) # reference
```

```
    # u = pid(r, y) # control signal
    # u + d # Plant input is control signal + disturbance
    # u =1
    e = x - [r; 0; 0]
    e[3] = 0 # torque not observable, just ignore it in the final feedback
    u = -L * e + d
    u = [maximum([-20 minimum([20 u])])]
end
t = 0:Ts:Tf


res = lsim(sysreal, ctrl, t)

plot(res, plotu=true, plotx=true, ploty=false);ylabel!("u", sp=1);ylabel!("x", sp=2);ylab
```



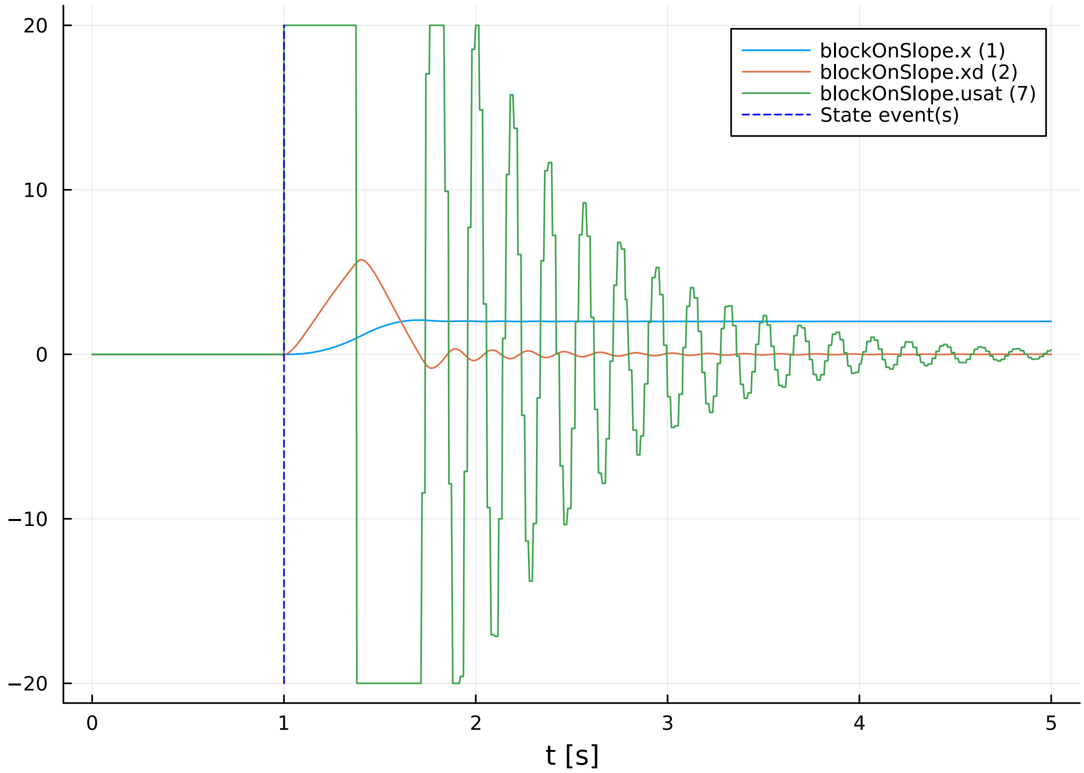
For more stats:

```
si = stepinfo(res);
plot(si);title!("Step Response")
```



We can also simulate it in a SIMULINK-like environment:

```
using FMI, DifferentialEquations
fmu = loadFMU(abspath("../modelica/ControlChallenges/ControlChallenges.BlockOnSl
simData = simulateME(fmu, (0.0, 5.0); recordValues=["blockOnSlope.x","blockOnSlo
unloadFMU(fmu);
plot(simData, states=false, timeEvents=false)
```



There is a slight difference between the `lsim` simulation and the FMU simulation. I need to recheck some stuff.