# 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];
B = [0
    0
    τ];
C = [1 0 0
    0 1 0];

sys = ss(A, B, C, 0.0)      # Continuous

plot!(bodeplot(tf(sys)),pzmap(tf(sys)))
```

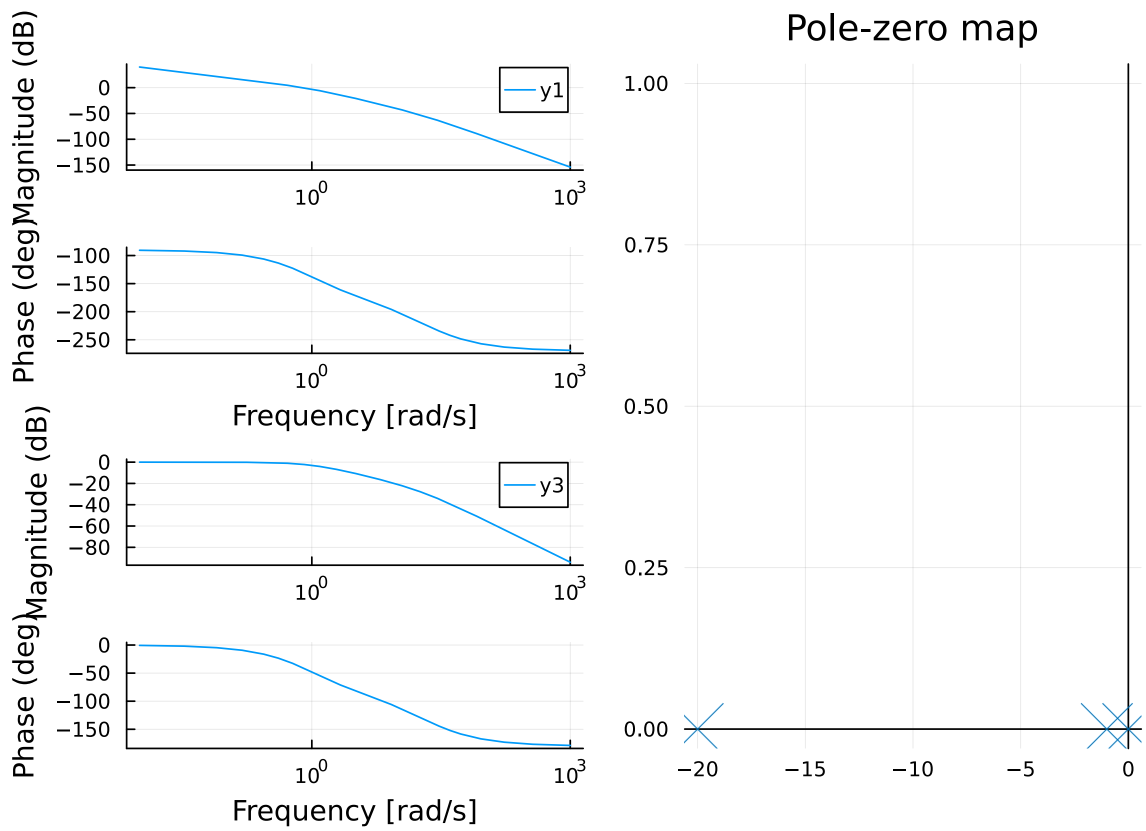



Figure 2.1: Starting Bode Plot

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))
```

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

Figure 2.2: Starting PZ map

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.

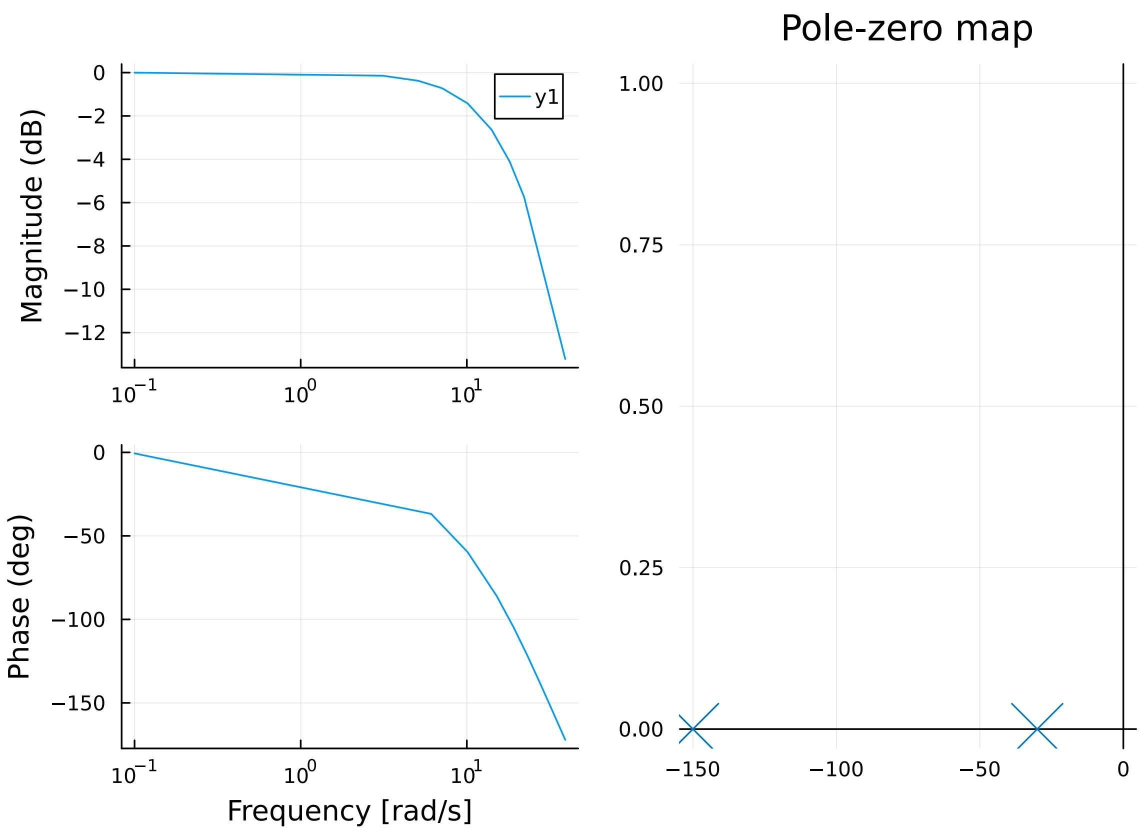
For some reason pole placement doesn't work for the observer, I use a Kalman Filter with random fast values.

```
observability(A, C).isobservable & controllability(A, B).iscontrollable; #OK

ε = 0.01;
pp = 15.0;
poles_cont = -2.0 * [pp + ε, pp - ε, pp];
L = real(place(sys, poles_cont, :c));

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

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

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

```
ComplexF64[-29.980000105166976 + 0.0im, -29.999999789554334 + 0.0im, -
30.020000105278555 + 0.0im, -150.00000000000009 + 0.0im, -150.09999999988327
149.90000000010167 + 0.0im]
```




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.

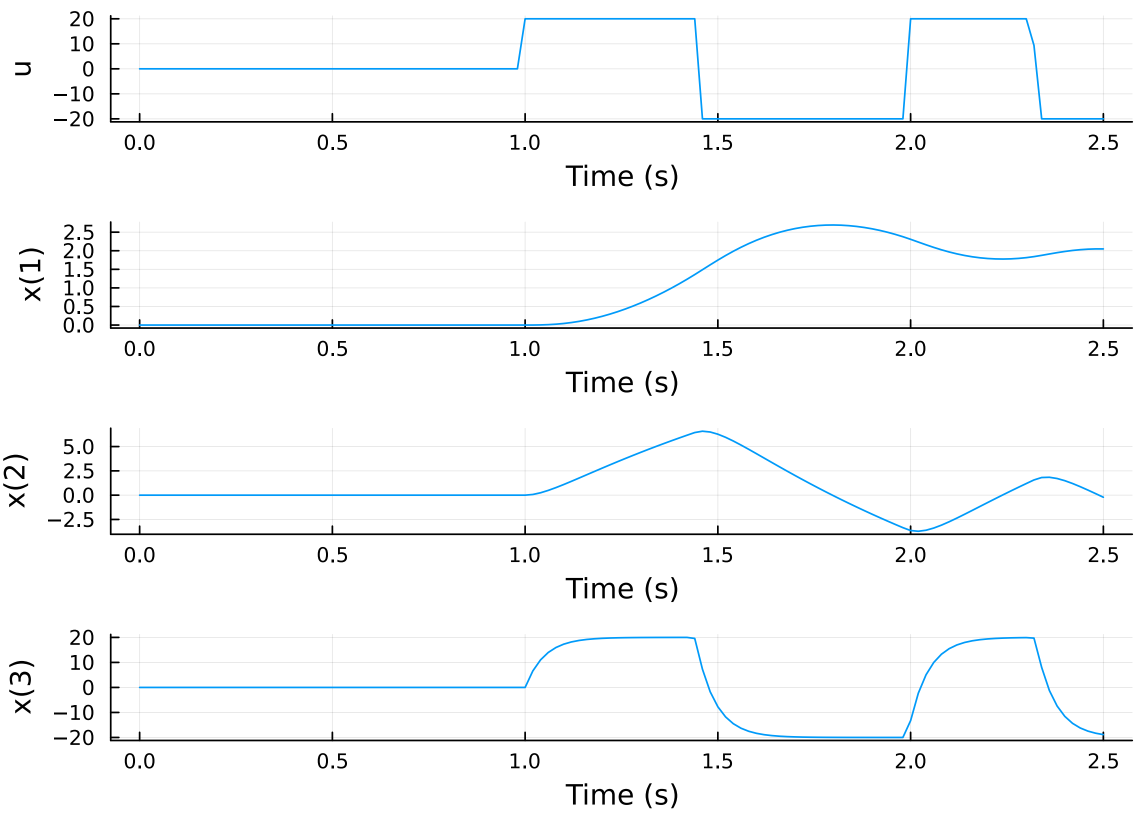
```
K = L[1];
Ti = 0;
Td = L[2] / L[1];
pid = DiscretePID(; K, Ts, Ti, Td);
```

## 2.3 Simulation

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

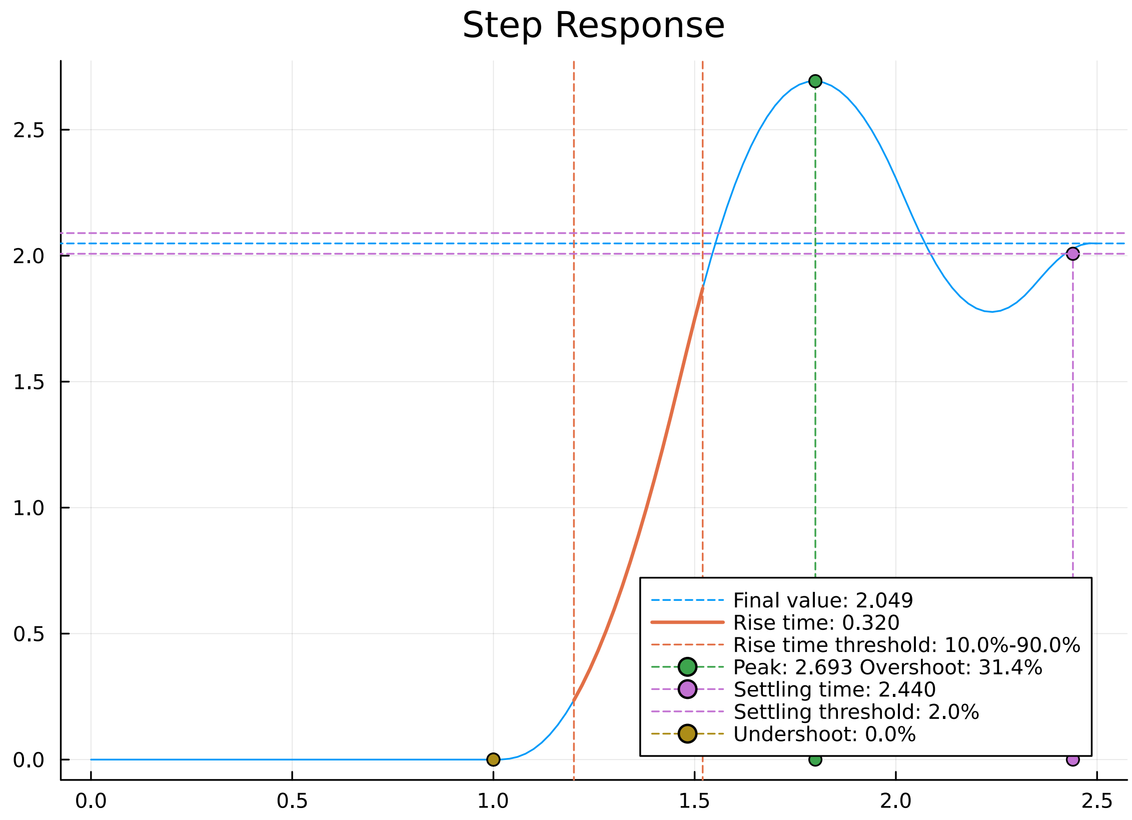
```
sysreal = ss(A, B, [1 0 0], 0.0)
ctrl = function (x, t)
    y = (sysreal.C*x)[] # measurement
    d = 0 * [1.0]        # disturbance
    r = 2.0 * (t ≥ 1) # reference
    # u = pid(r, y) # control signal
```

```
    # u + d # Plant input is control signal + disturbance
    # u =1
    e = x - [r; 0.0; 0.0]
    e[3] = 0.0 # torque not observable, just ignore it in the final feedback
    u = -L * e + d
    u = [maximum([-20.0 minimum([20.0 u])])]
end
t = 0:Ts:Tf

res = lsim(sysreal, ctrl, t)

display(plot(res,
    plotu=true,
    plotx=true,
    ploty=false
    ))
ylabel!(
    "u", sp=1);ylabel!(
    "x", sp=2);ylabel!(
    "v", sp=3);ylabel!(
    "T", sp=4);
```



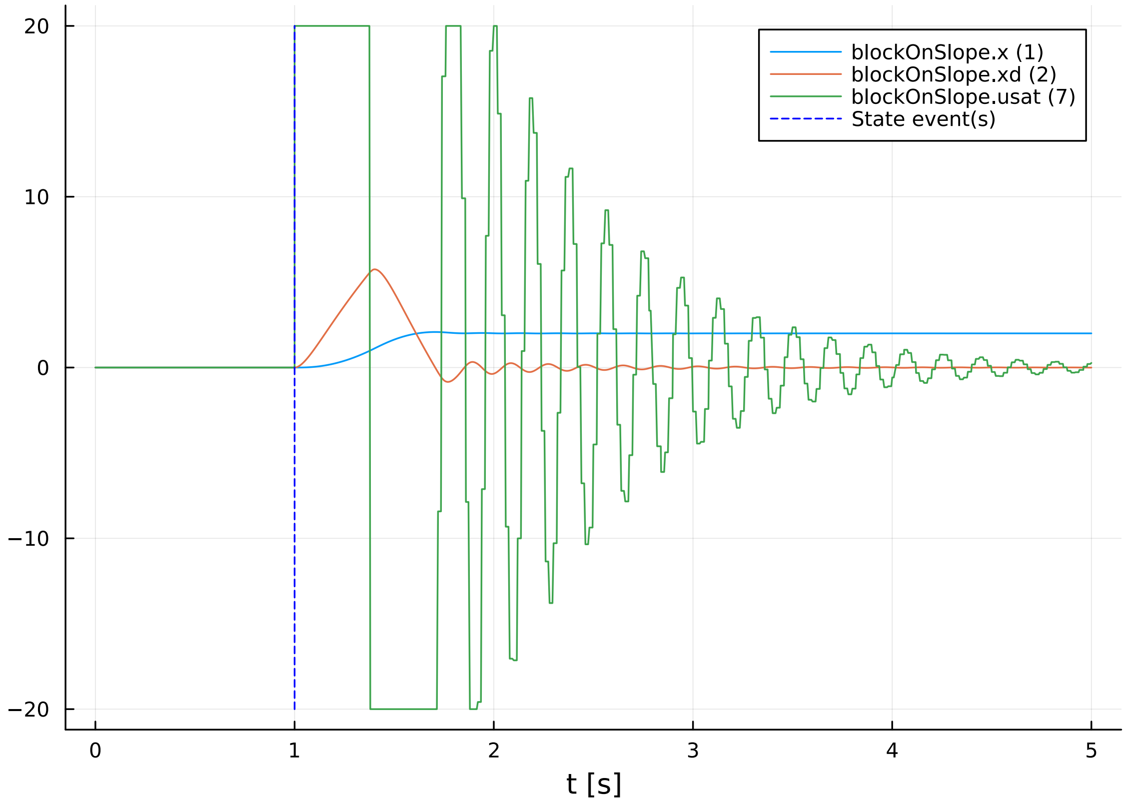
For more stats:

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




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

```
using FMI, DifferentialEquations
fmuPath = abspath(joinpath(@__DIR__,
    "..",
    "modelica",
    "ControlChallenges",
    "ControlChallenges.BlockOnSlope_Challenges.Examples.WithFriction.fmu"))
fmu = loadFMU(fmuPath);
simData = simulateME(
    fmu,
    (0.0, 5.0);
    recordValues=["blockOnSlope.x", "blockOnSlope.xd", "blockOnSlope.usat"],
    showProgress=false);
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.