ROTARY INVERTED PENDULUM
CONTROLLED WITH FLC, PID AND FSF

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Presented to Prof. Youssef Harkouss

Guideline

- Introduction
- Controllers
  - *Fuzzy Logic Controller*
  - *PID Controller*
  - *Full State Feedback Controller*
- Modeling of Rotary Inverted Pendulum
- Controlling the Pendulum
  - *Fuzzy Logic*
  - *PID*
  - *Full State Feedback*
  - *Results*
- Conclusion
  - *Summary*
  - *Perspective*

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Guideline

- Introduction

Introduction

- Control systems are found all around
- Used in variety of different applications
- Different techniques differ hugely in both complexity and performance

Introduction

- Objective
  - *Study the behavior of some control techniques on a rotary inverted pendulum*
  - *Compare the results of the controllers*

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Guideline

- Controllers

Controllers

- In this chapter we will introduce the concepts behind the controllers used

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- Controllers
  - *Fuzzy Logic Controller*

Fuzzy Logic Controller

- Uses Fuzzy Logic
- Deals with analog inputs and produces an output based on specified membership functions and rules
- Term “fuzzy” refers to the fact that logic involved can deal with partially true or partially false instead of discrete states

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- **Controllers**
  - *PID Controller*

PID Controller

- Commonly used in many applications
- Consist of three different controllers whose outputs are summed:
  - *Proportional*
  - *Integral*
  - *Derivative*

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- **Controllers**
  - *Full State Feedback Controller*

Full State Feedback Controller

- Uses several algorithm to attain control
  - *Here we use Linear-Quadratic Regulator*
- LQR provides a solution to minimize the cost function

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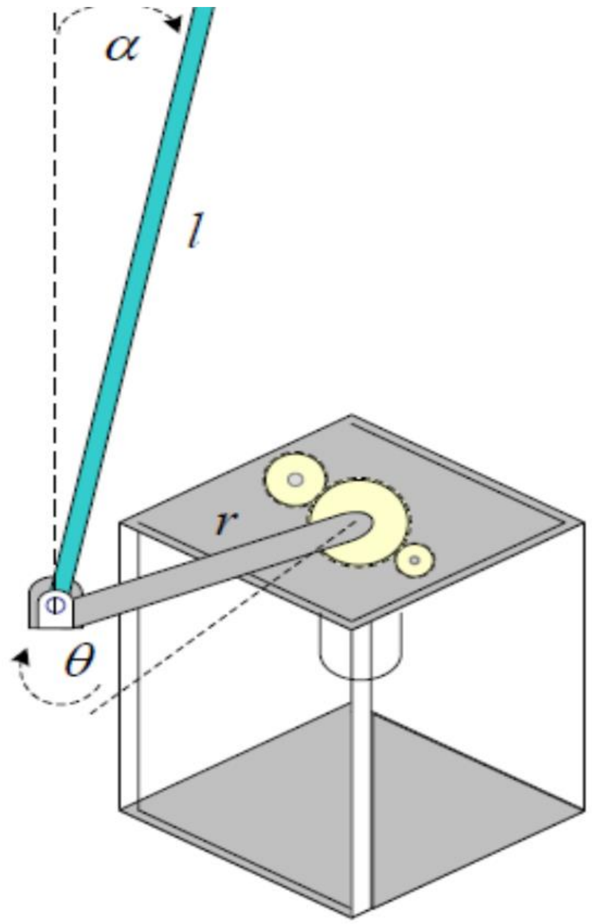
- Modeling of Rotary Inverted Pendulum



MODELING OF ROTARY INVERTED PENDULUM

Modeling of Rotary Inverted Pendulum

- Model was provided by the manufacturer of the kit and has the form:
- $\begin{cases} \dot{X} = AX + Bu \\ Y = CX + Du \end{cases}$ Where:

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \dfrac{M_p^2 \cdot l_\rho^2 \cdot r \cdot g}{J_{eq} \cdot M_p \cdot l_p^2 + M_p \cdot r^2 \cdot J_p + J_{eq} \cdot J_p} & -\dfrac{(J_p.K_t.K_m + M_p.l_p^2.K_t.K_m)}{R_m.(J_{eq}.J_p + J_{eq}.M_p.l_p^2 + M_p.r^2.J_p)} & -B_{eq} \\ 0 & \dfrac{M_p.l_p.g(J_{eq} + M_p.r^2)}{J_{eq} \cdot M_p \cdot l_p^2 + M_p \cdot r^2 \cdot J_p + J_{eq} \cdot J_p} & -\dfrac{M_p.l_p.r.K_t.K_m}{R_m.(J_{eq}.J_p + J_{eq}.M_p.l_p^2 + M_p.r^2.J_p)} & -B_p \end{bmatrix} \quad C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ -\dfrac{K_t.(J_p + M_p.l_p^2)}{R_m.(J_{eq}.J_p + J_{eq}.M_p.l_p^2 + M_p.r^2.J_p)} \\ -\dfrac{M_p.l_p.r.K_t}{R_m.(J_{eq}.J_p + J_{eq}.M_p.l_p^2 + M_p.r^2.J_p)} \end{bmatrix} \quad D = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

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- Controlling the Pendulum

Controlling the Pendulum

- Simulated on MATLAB and Simulink according to the provided model
- The scope of this project focuses only on the balance controller of the pendulum
- Initial Conditions are:
  - $\theta = 0$ $\alpha = 0.2$ $\dot{\theta} = 0$ $\dot{\alpha} = 0$

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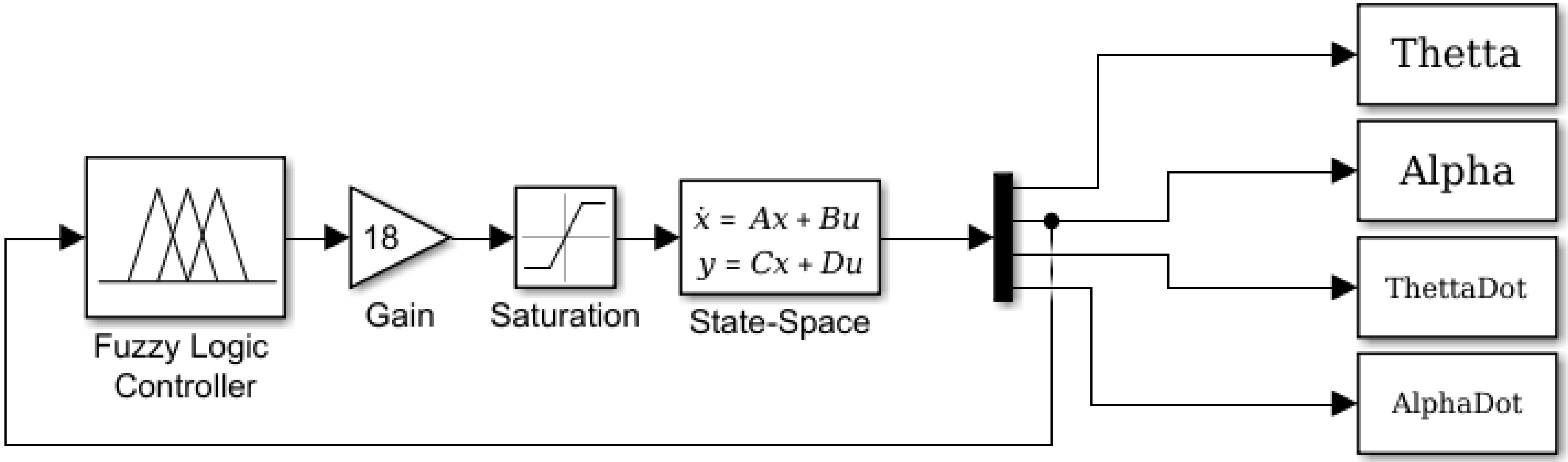
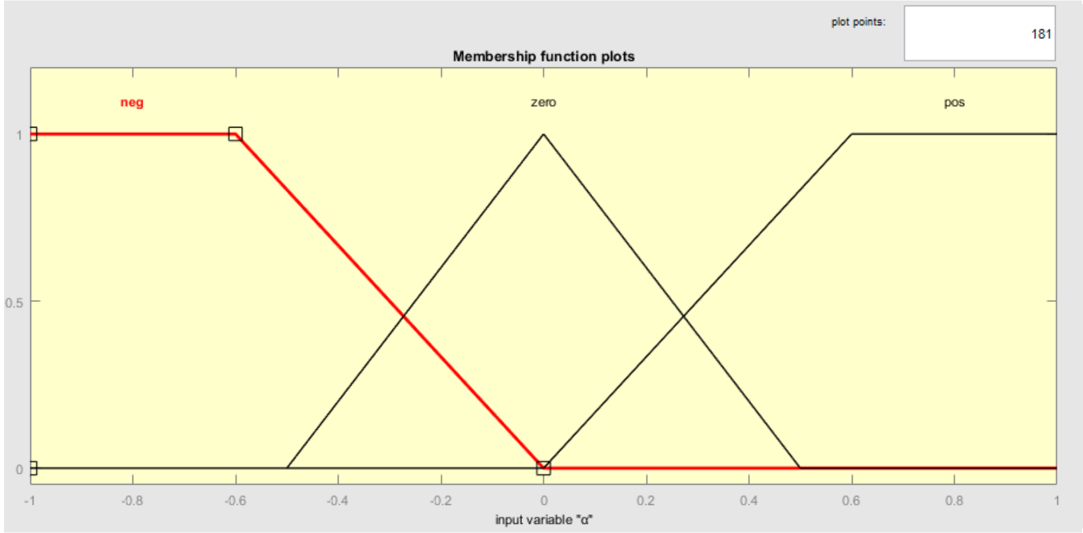
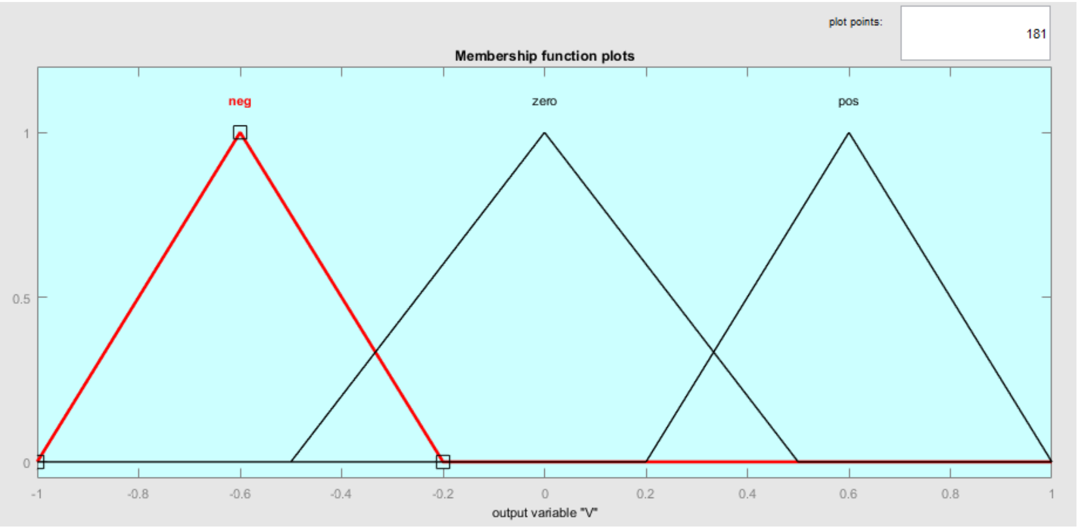
- **Controlling the Pendulum**
  - *Fuzzy Logic*


Thetta
Alpha
ThettaDot
AlphaDot
18
Gain
Saturation
$\dot{x} = Ax + Bu$
$y = Cx + Du$
State-Space
Fuzzy Logic
Controller

FUZZY LOGIC



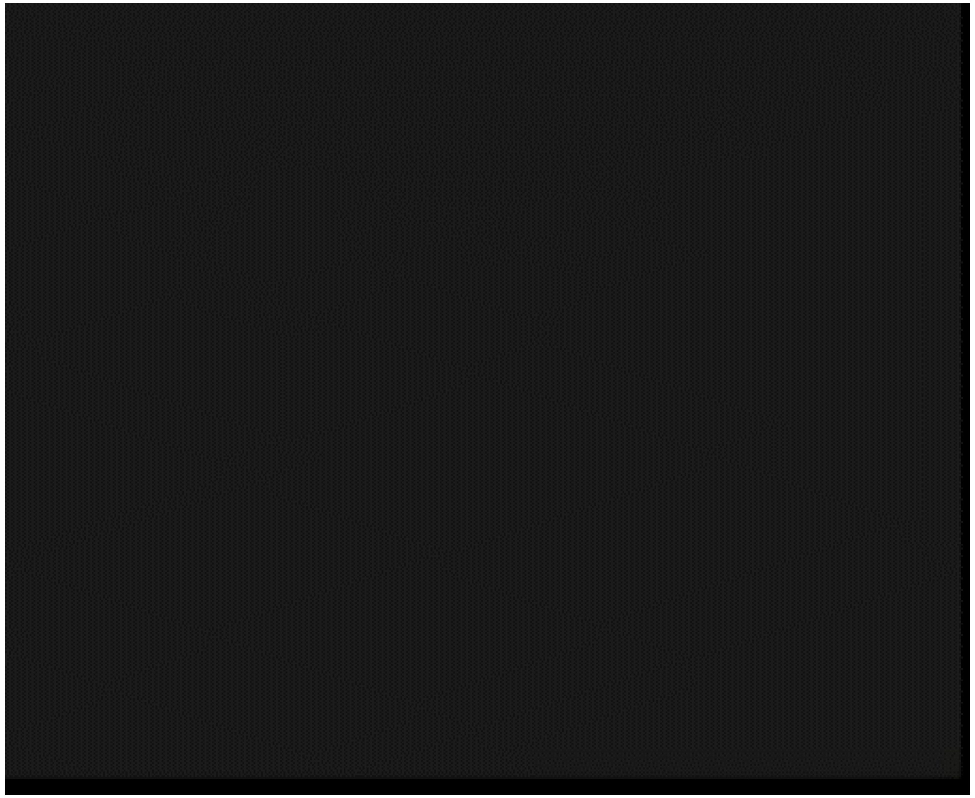


- If input is pos, then output is pos
- If input is zero, then output is zero
- If input is neg, then output is neg

defuzzied using centroid method

FUZZY LOGIC

Fuzzy Logic



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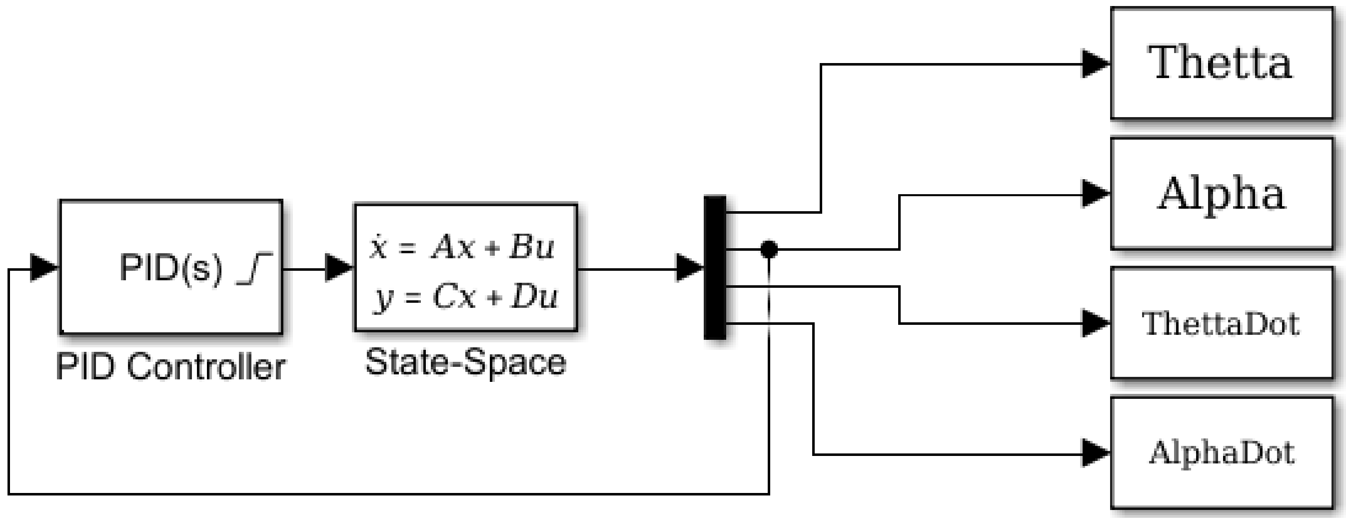
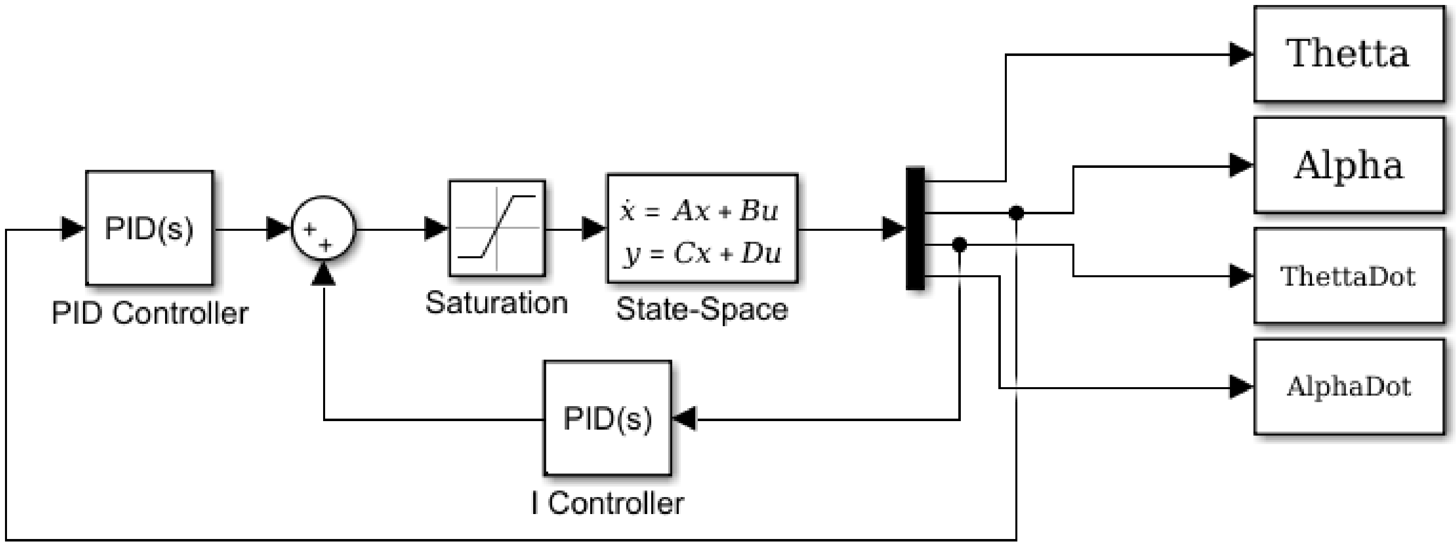
- Controlling the Pendulum
    - *PID*


PID(s)
PID Controller
$\dot{x} = Ax + Bu$
$y = Cx + Du$
State-Space
Thetta
Alpha
ThettaDot
AlphaDot

PID

PID


PID(s)
PID Controller
Saturation
$\dot{x} = Ax + Bu$
$y = Cx + Du$
State-Space
PID(s)
I Controller
Thetta
Alpha
ThettaDot
AlphaDot

PID

PID

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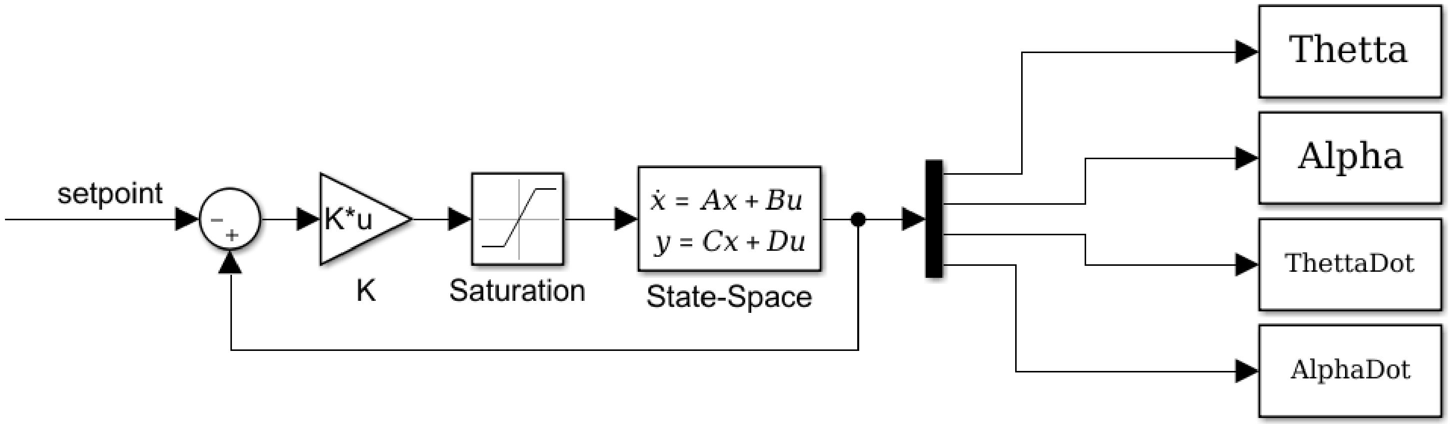
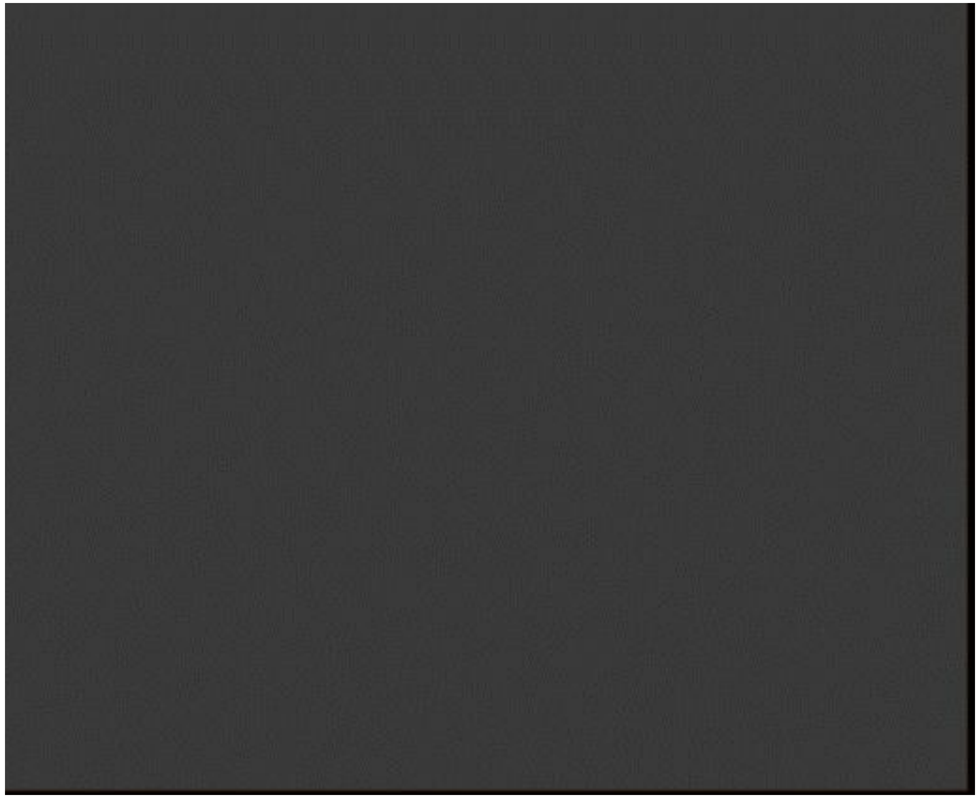
- Controlling the Pendulum
  - *Full State Feedback*

Full State Feedback



- $Q = \begin{bmatrix} 3 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 5 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$
  R = 1
- K is calculated using lqr function in MATLAB

Full State Feedback



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- Controlling the Pendulum
  - *Results*

Results

- FLC couldn't keep the pendulum balanced
- PID was able to stabilize the pendulum but the arm kept spinning without adding another PID controller
- FSF using LQR was able to provide smooth balancing of the pendulum along with setting reference points for the arm to follow

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- **Conclusion**
  - *Summary*

Summary

- FLC proved its near impossibility to control complex systems
- PID proved that it is a controller that is simple enough yet effective enough in most cases
- FSF using LQR showed excellent performance and proved its ability to tackle complex systems with ease

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Perspective

- Design a more advanced controller using PID as building blocks
- Implementing a swing up and catch controller
  - *Might utilize different controllers*
  - *Dealing with the nonlinear aspect of the system*
  - *Combine the different controllers and switching*
- Implementing the controllers on physical hardware

THANK YOU FOR YOUR TIME

Feel free to reach out by email for any question