Course Project - Part I

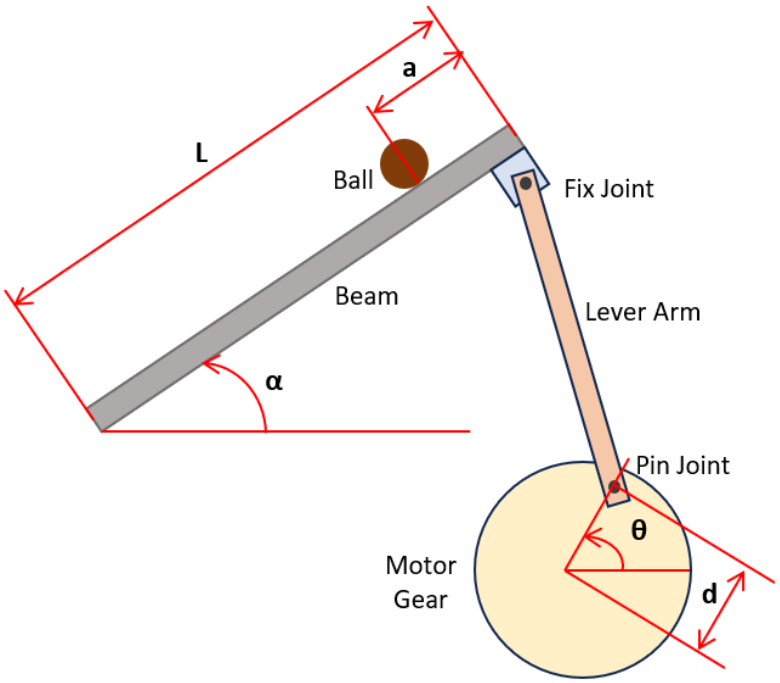
ES 245: Fall 2024 Term

Title: Ball and Beam

Problem Statement: As shown in the figure below, a ball is placed on a beam, where it rolls under the influence of gravity. The ball has one degree of freedom along the length of the beam. The beam's angle is adjusted using a lever arm connected to the beam at one end and to a servo motor gear at the other. As the servo gear rotates by an angle $\boldsymbol{\theta}$ about its axis, the lever arm angle changes by $\boldsymbol{a}$ from the horizontal.

Assumptions: The ball remains in contact with the beam at all times. The ball performs pure rolling motion (rolling without slipping)

Objective: Design a controller to manipulate the ball's position on the beam, with the input being the servo gear angle and the output being the ball's position.



Reference Videos:

1. https://www.youtube.com/watch?v=y5Hmr-rR-yk
2. https://www.youtube.com/watch?v=gfOChWXEgq4
3. https://www.youtube.com/shorts/0JT0tff6nsA

Team: a team of four students will be formulated by the TAs

Submission: a technical report and the CAD drawings, programming scripts, and physical setup must be submitted.

Task 1: Define the system

1.1 Write the system dynamics equations.

1.2 Write the system's transfer function between motor gear angle ***(θ)*** and ball position ***(a)***.

1.3 Linearlize the system equations and write in the state space form.

Task 2: Analysis of the system

Assume suitable values of the parameters in the transfer function, including the mass of the ball (m), radius of the ball (R), lever arm offset (d), length of the beam (L), ball's moment of inertia (J), ball's position on beam (a), beam angle, and servo gear angle.

2.1 Perform the following analysis using MATLAB

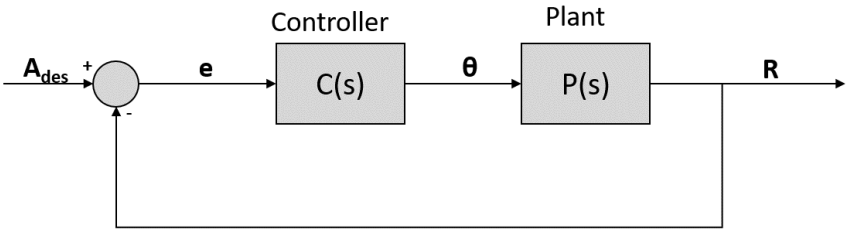
- Plot poles/zeros
- Plot open loop step response *(servo gear angle in 1 radian step)*

2.2 Identify the type of the system and mention your observation from the poles/zeros plot and the open loop response of the system.

Task 3: PID control

3.1 Design a controller with unity feedback and plot the performance of the following controllers for varying gains:

- Proportional controller
- Proportional-derivative controller
- Proportional-integral-derivative controller



3.2 Mention your observations on all three controller types and how they affect transient response, steady-state response, and set point error.

3.3 Design a controller to follow the following criteria - settling time less than 3 seconds and overshoot less than 5%.

Task 4: Simulation of ball and beam in MATLAB

4.1 Build the ball beam model in Simulink and generate the system's open loop response.

4.2 Linearize the model and design a compensator to meet the following design criteria - overshoot of less than 5% and settling time of less than 5 seconds. Generate the system's closed-loop response.

4.3 Develop a Simscape model for the ball beam system.

Task 5: Physical System

5.1 Develop a CAD model of the system and build the physical system.

5.2 Design a PID controller to stabilize the ball on the beam at the given distance from the end. Comment on your observations and challenges in implementing the PID control.