Study the effects of different controllers on a Yo-Yo

Team number: 5

INTRODUCTION:

The primary goal of this research and development initiative is to pioneer advancements in the modeling and control of dynamic yoyos, integrating principles from physics, control theory, and engineering. Our aim is to create an innovative yoyo toy with the capability to execute a distinctive pulling back motion, targeting a diverse audience, including hobbyists, educators, and entertainment enthusiasts. Employing a multidisciplinary approach, we seek to harmoniously blend theoretical principles with practical applications, pushing the conventional boundaries of yoyo design and performance.

The yoyo, often perceived as a simple toy, has universally captivated individuals through its rhythmic up-and-down motion, governed by gravity, tension, and rotational forces. Despite its apparent simplicity, the yoyo conceals dynamic intricacies that have fascinated both enthusiasts and scholars. In our exploration of dynamic systems and control mechanisms, this project meticulously examines the yoyo's behavior, with a specific emphasis on the intriguing phenomenon of its pulling back motion.

The dynamics of a yoyo in motion are intricate, involving the interplay of gravity, tension, and rotational forces. One frequently underestimated factor in this dynamic system is friction. Friction, a ubiquitous force in mechanical systems, significantly influences the yoyo's movement, affecting spin rates, altering trajectories during descent, and playing a crucial role in the pulling back motion. Recognizing the pivotal role of friction, this project is committed to a detailed examination of its effects on yoyo dynamics. By integrating friction into our modeling and control strategies, we aim to uncover subtle interactions between forces, providing a comprehensive understanding of the yoyo's behavior.

Beyond theoretical exploration, our objective is to develop robust mathematical models that accurately capture the dynamic interplay between gravity, tension, rotational forces, and friction. Additionally, we aim to formulate control strategies that leverage this understanding to influence the yoyo's trajectory during the pulling back phase. The inclusion of friction in our analysis adds a practical dimension, aligning our work with real-world scenarios where friction is a constant force influencing mechanical systems.

BACKGROUND:

Importance of the problem:

The significance of this project lies in the challenge of modeling and controlling a dynamic yoyo, a task that extends beyond traditional control systems. Unlike conventional systems, developing a robotic counterpart for a toy like a yoyo presents distinct challenges, such as the absence of sensors to measure toy motions and the lack of well-established mathematical models. This problem is not merely a technical hurdle; it represents an opportunity to explore new frontiers in control theory and robotics, providing valuable insights into managing dynamic and discontinuous tasks with limited sensor information.

Techniques used:

Traditional control systems predominantly rely on continuous-time feedback control. However, this approach encounters significant challenges in the context of a yoyo, including discontinuities at the bottom, difficulties in measuring state variables, motion constraints, and integral-type constraints. To address these issues, the project proposes leveraging alternative control methods to design an effective controller for dynamic yoyo manipulation. This requires a departure from conventional methodologies and a creative integration of principles from various domains.

OBJECTIVES:

Primary Objectives:

Real-Time Friction Detection: Our primary goal is to develop a controller capable of real-time detection and adjustment of frictional losses within a yoyo system.

Feedback Mechanism: To enhance adaptability, our controller will establish a dynamic feedback loop, enabling adjustments to operating parameters in real-time. This ensures a proactive approach to minimizing friction-induced losses.

Main Objective:

Ensure continuous and stable vertical motion of the yo-yo despite the presence of external forces, such that the yo-yo moves up and down with controlled dynamics.

Assumptions

To simplify the analysis, the following assumptions are made:

- Assumption 1: The diameter and mass of the string are neglected.
- Assumption 2: The string is always vertical. The mass center moves only in the vertical direction. The direction of the rotational axis is constant and orthogonal to the vertical axis.
- Assumption 3: All frictions are viscous frictions, proportional to the rotational velocity of the yoyo.
- Assumption 4: The rotational velocity of the yoyo does not change at the bottom. The rotation of the yoyo at the bottom is neglected.

PROJECT DESIGN:

Yo-yo model and controller design:

Force equations:

Parameters:

θ: Angular displacement.

$\dot{\theta}$: Angular velocity (the derivative of θ with respect to time).

$\ddot{\theta}$: Angular acceleration (the second derivative of θ with respect to time).

u: External torque or force acting on the system.

m: Mass of the system.

r: Distance from the axis of rotation to the point where the force or torque is applied.

g: Acceleration due to gravity.

I: Moment of inertia of the system.

$$\ell = r\theta = h - z. \qquad (1)$$

$$m\ddot{z} = -mg + T, \qquad I\ddot{\theta} = rT - r\epsilon\dot{\theta}. \qquad (2)$$

$$\ell = L - r\theta, \qquad (3)$$

$$I\ddot{\theta} = -rT - r\epsilon\dot{\theta}. \qquad (4)$$

$$(I + mr^2)\ddot{\theta} = \pm mr(\ddot{h} + g) - r\epsilon\dot{\theta}, \qquad (5)$$

$$\ddot{\theta} = \frac{\pm(u+mrg)-r\cdot e\cdot\dot{\theta}}{I+m\cdot r^2}$$

This has been derived from the equations given in the research paper [1].

Now to convert to state space representation we have clubbed the u and m*g*r term together so as to reverse the sign for going up and down. Hence, this m*g*r ter adds to the complexity of the system because it is not represented in the state space equations;

State Space equations:

State variables: [θ θ̇] (angular displacement and angular velocity)

A = [0 ,1; 0, -(e*r)/(I + m*r^2)];

B = [0; 1/(I + m*r^2)];

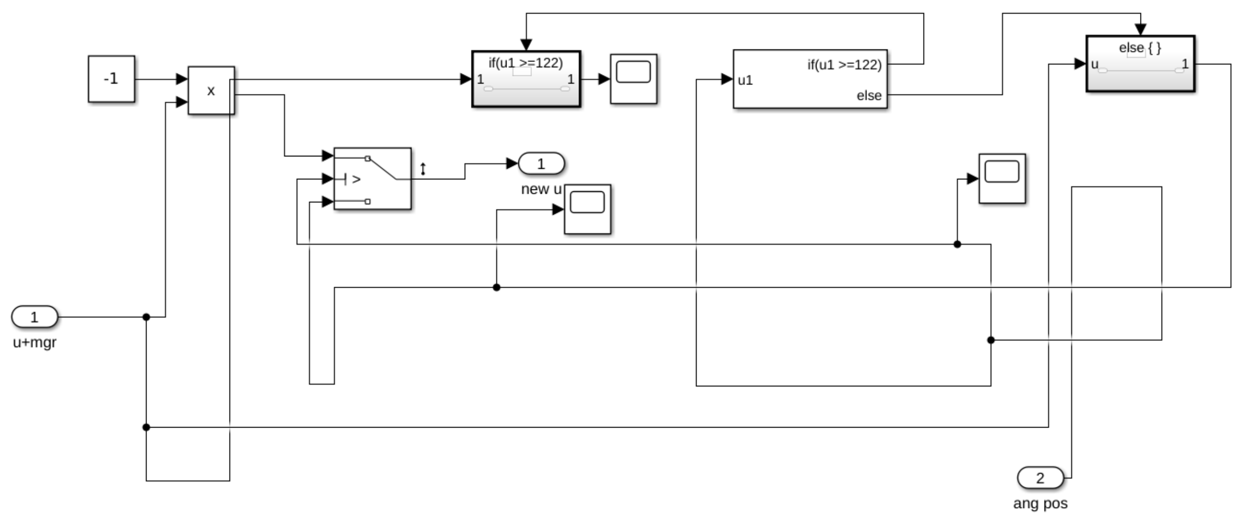
C = [1 ,0];

D = 0;

Approach:

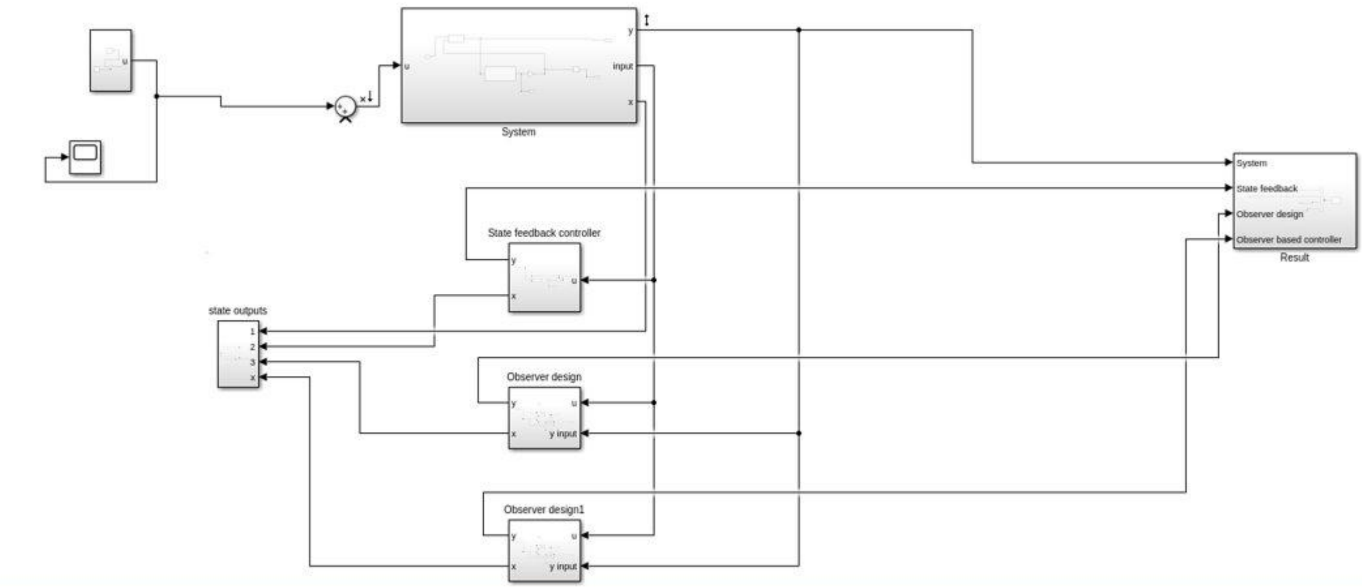
The most difficult part of the project was designing the system for this model. Since the constraint for length is not being specified in the state space we need to explicitly pull back the yoyo after it reaches a certain angular position that is almost after 120 radians that is equal to approximately 20 rotations of the yoyo.

Since the input depends on the output depending on whether it is in the up motion or down motion we cannot use the ode45 function or any loop iteration technique and this problem specifically requires Simulink.

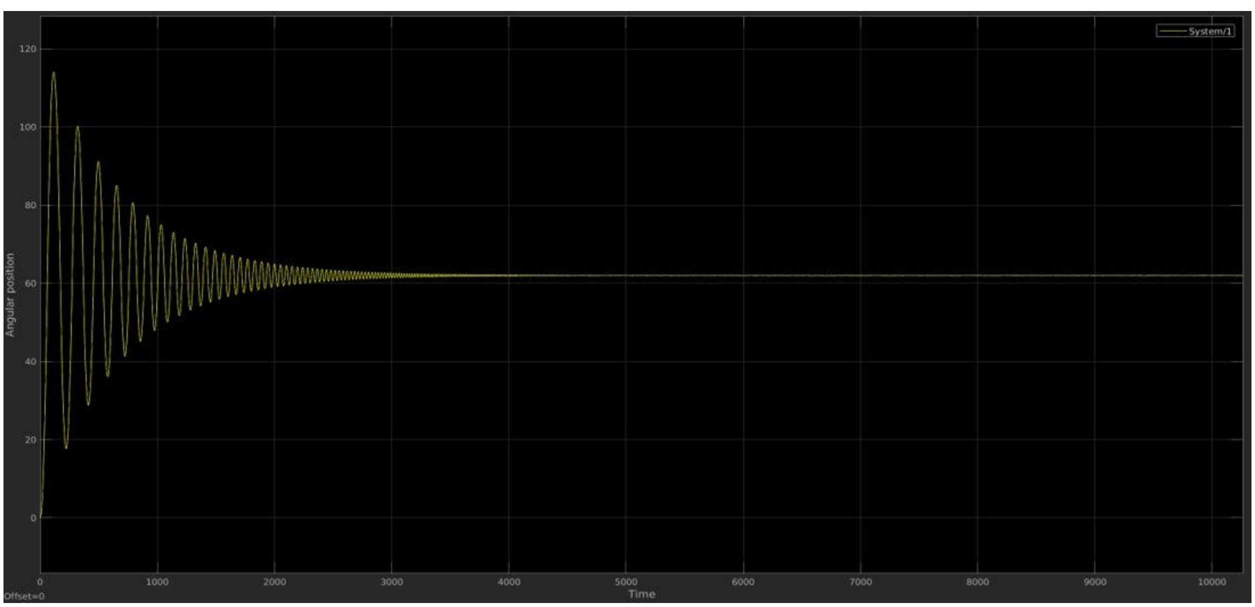


Model for system control

This subsystem checks when the angular position reaches 20 rotations and then sends out a signal to switch the input to a negative or positive value after reaching the bottom/top.



Simulink model



Output of system

Controllers:

State feedback controller

Most challenging steps were to locate the approx desired poles for the calculation of K. If we want to completely eliminate friction we need the desired poles to be [0 0]..

So K was calculated by the function ‘acker’.

```
K =

   1.0e-04 *


        0   -0.7000
```

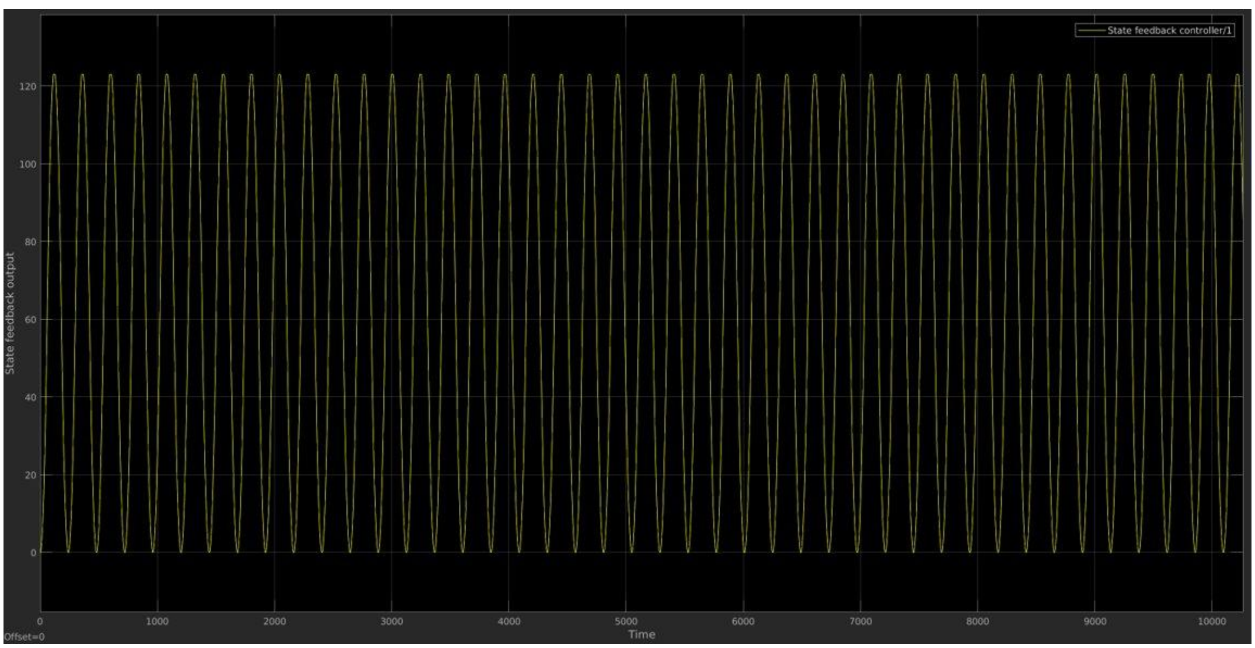
The state equation was modified as

A_st=A-BK

B_st=B

C_st=C

This gives an ideal yo-yo motion with 0 external input.



Output of state feedback

<u>Observer Design</u>

For designing L we have taken poles as [-0.01 -0.01] which is almost 10 times further than the characteristic eigen values . Again we used 'acker' to calculate L

L= 1.0e-03 *

0.0031

0.5444

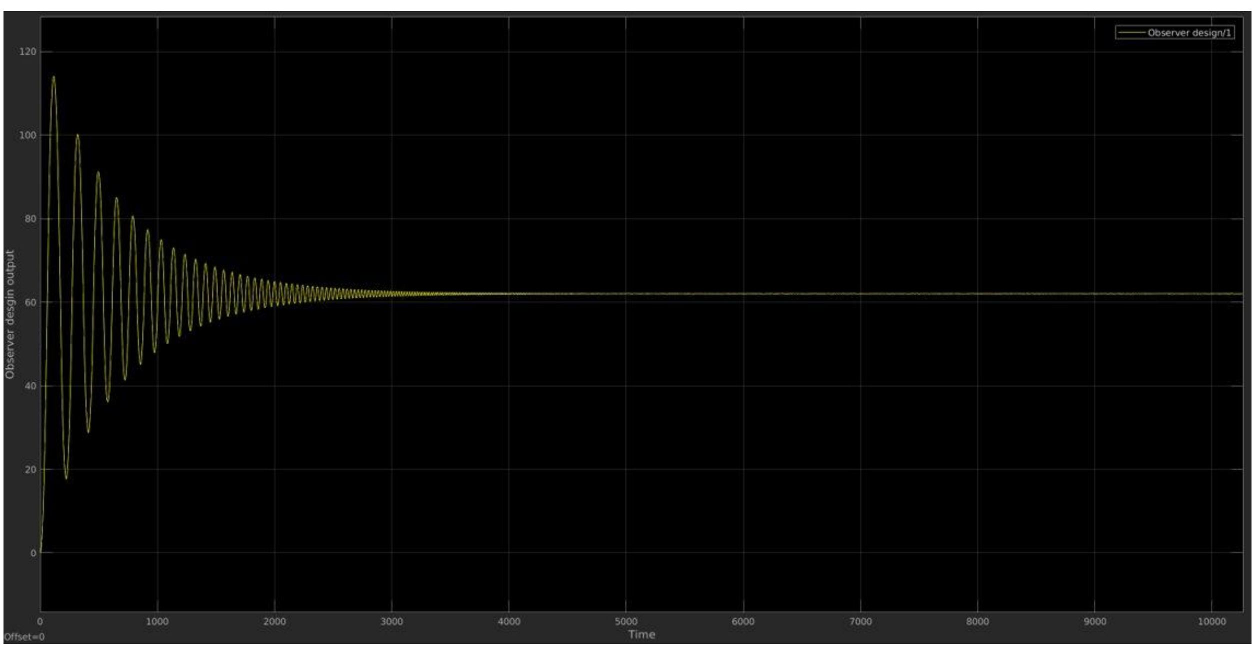
The state equation was modified as:

A_obs=A-LC

B_obs= [B L] *(this done so that B is multiplied by u and L is multiplied by y)*

C_obs=C

D_obs=[0 0;0 0]



<u>Observer output</u>

<u>Observer based controller</u>

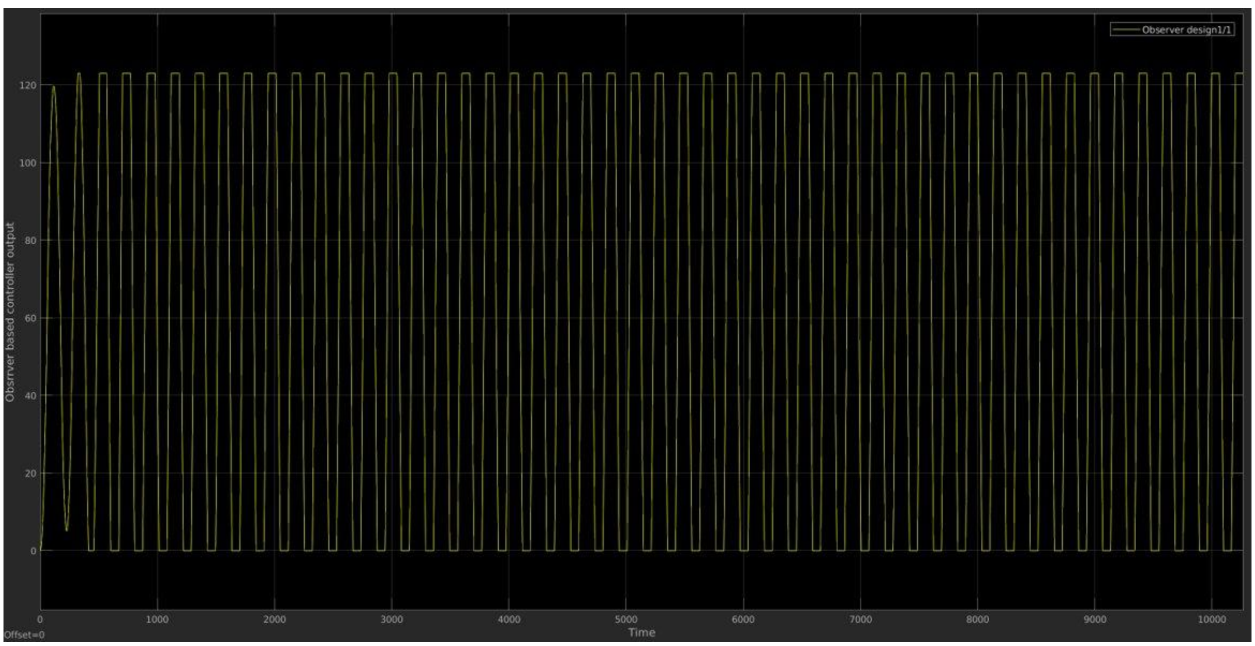
Based on the L and K values calculated above, we change the equations as follows

A_osc=A-BK-LC

B_osc=[0 L]

C_osc=C

D_osc=D



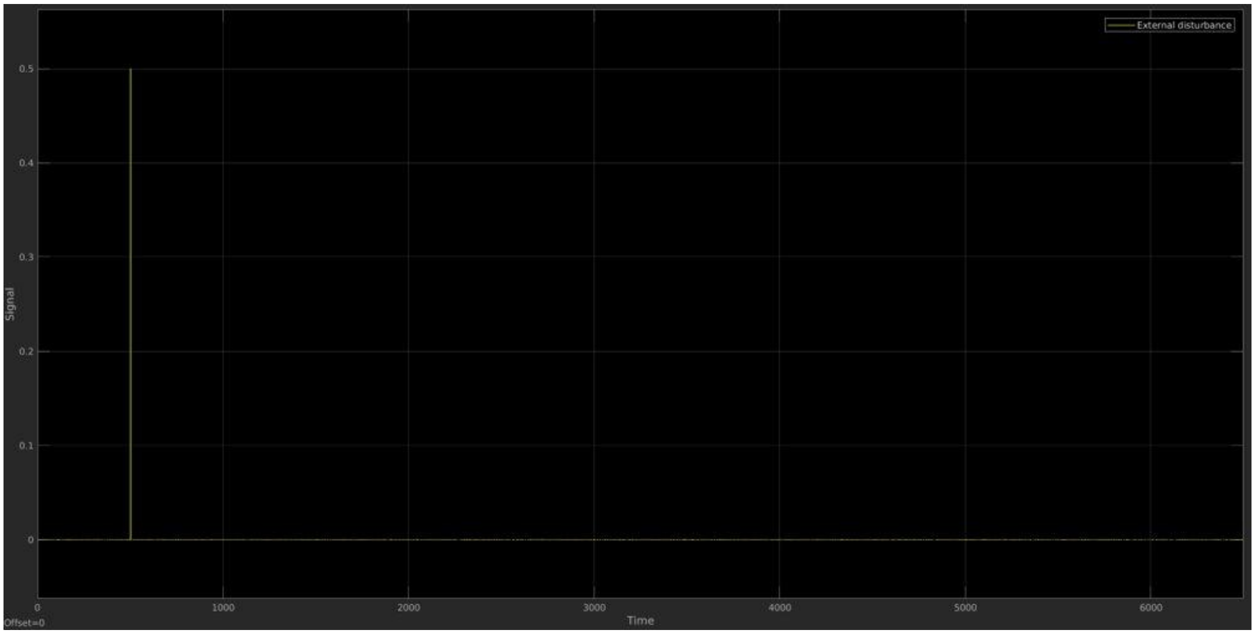
<u>Observer based controller output</u>

ANALYSIS OF THE WORK:

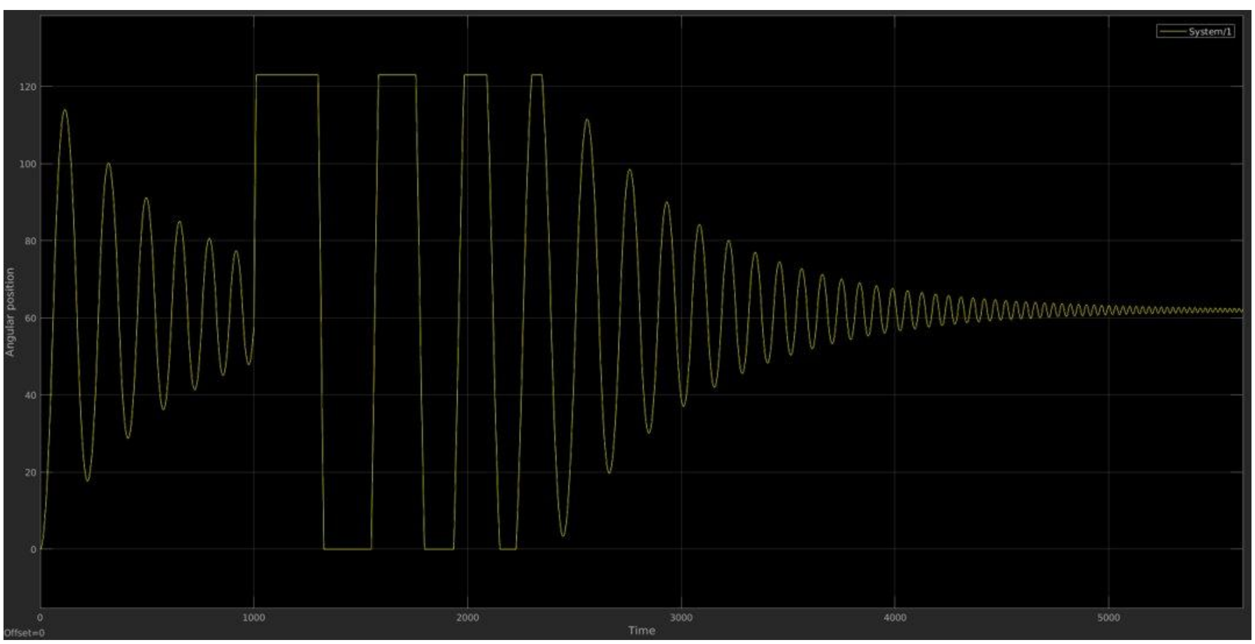
<u>Test case:</u>

To test our model we have given an impulse for one second of 0.5 N at the 500 second time stamp.

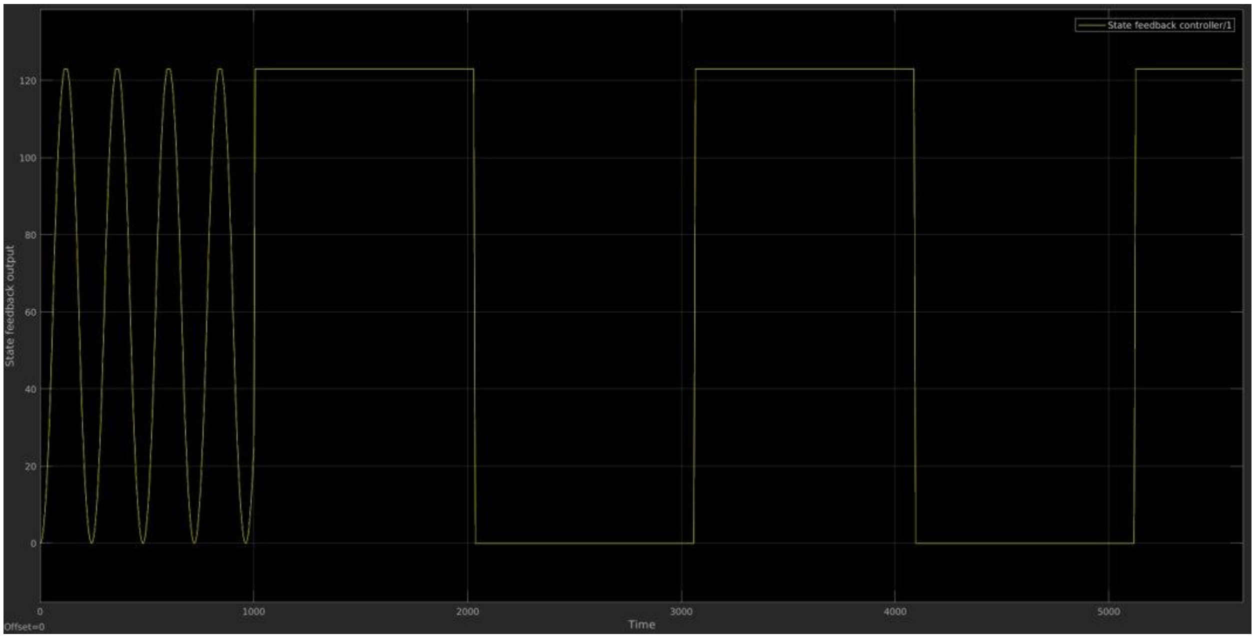
Outputs of the system and controllers:



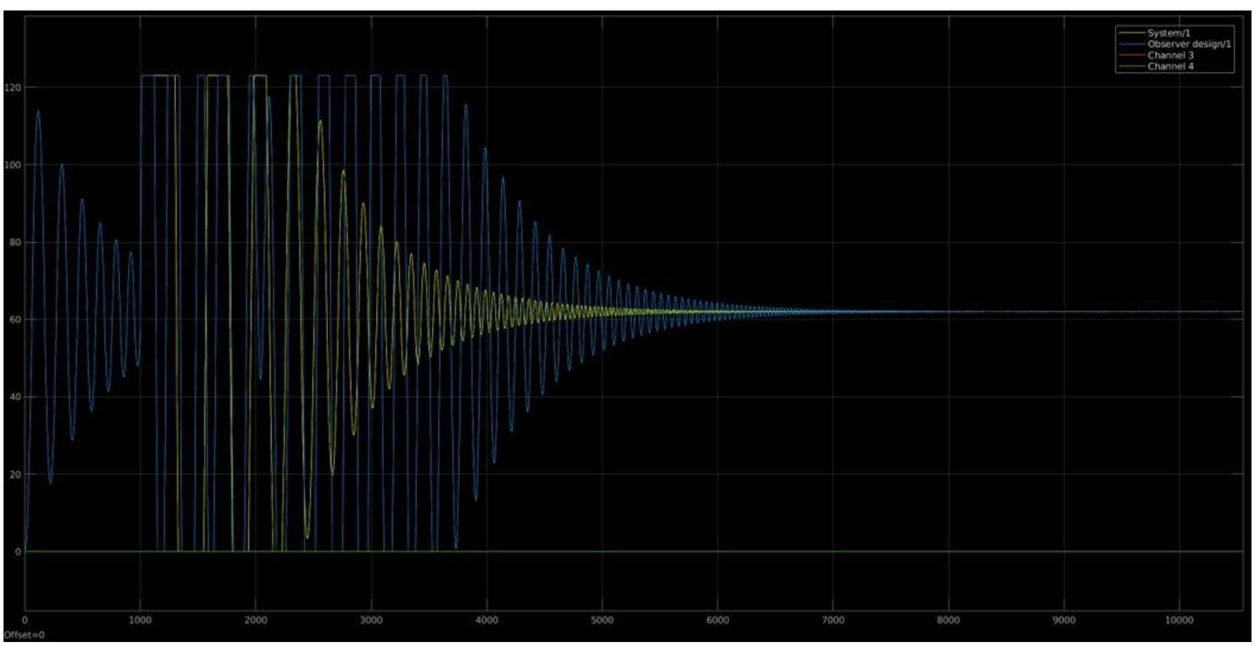
Impulse signal



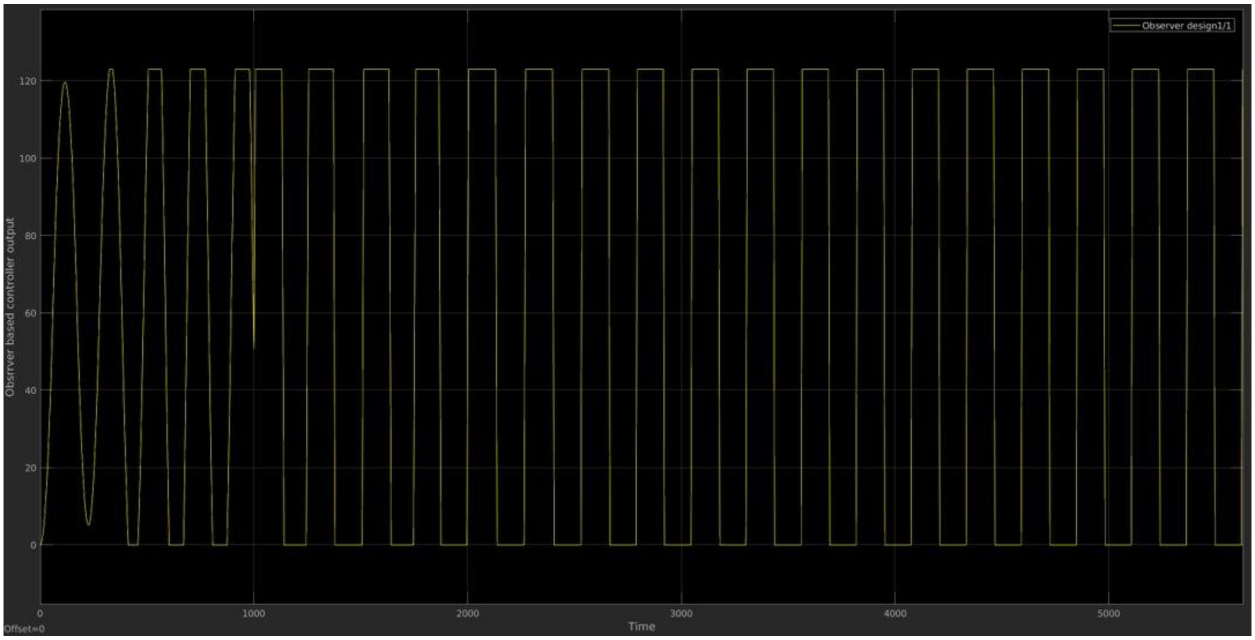
System output



State feedback output



Observer design output (blue) and system output (yellow)



<u>Observer based controller</u>

Analysis:

The observer helps us retain the shape of the graph whereas the state feedback helps us decide the ideal waveform and integrating those two together gets us the ideal control.

Challenges encountered:

Several challenges were encountered during the project. Dealing with discontinuities at the bottom, difficulties in measuring state variables, and constraints related to yoyo manipulation were among the prominent obstacles. These challenges prompted a departure from traditional control methods, leading to the exploration of alternative control strategies capable of addressing the unique requirements of the task.

The implementation of the project provided valuable insights into the limitations of traditional control methods when applied to dynamic and discontinuous tasks. One key takeaway is the recognition of the critical role visual feedback plays in conjunction with control algorithms. This realization emphasizes the necessity of adopting a holistic approach to robotic toy manipulation, where sensory inputs complement control strategies. visual feedback here could have been a key sensory input to know when the yoyo is stretched to its maximum..

Code specific problems:

- As input is bidirectional, it must be modified each time the length requirements is achieved.
- Ode 45 cannot be used since the input must be modified each time the length criterion is met.
- To acquire more and continuous outputs, the refine factor had to be changed.
- Constant mgr term was added and needed to be combined with the input.

NEXT STEPS IN THE PROJECT:

If the project were to continue, we would actually get rid of all assumptions like mass of string and radius of string and incorporate all of this in the state space equation. Also for this project we only made the yoyo go up and down, a more complex problem would be if the yoyo also made an angle with the ground.

CONCLUSION:

We have achieved the successful construction of a yoyo model with the capability of accepting input from both directions. This innovative design allows the yoyo to endure external forces without any interference with its ongoing motion. What sets our accomplishment apart is that we are among the first to create a yoyo that remains functional and continues its operation, regardless of the presence of external inputs or forces. This breakthrough highlights the resilience and stability of our yoyo model, making it a significant advancement in the field.

<u>Team member contribution:</u>

Aditya Aspat: MATLAB script ,Entire Simulink model, Report and Presentation

Varun Khatri: Controller design, Report and Presentation

Shubhangi Pulipati: Report and Presentation

Siddharth Lad: Report and Presentation

CITATION:

[1] K. Hashimoto and T. Noritsugu, "Modeling and control of robotic yo-yo with visual feedback," Proceedings of IEEE International Conference on Robotics and Automation, Minneapolis, MN, USA, 1996, pp. 2650-2655 vol.3, doi: 10.1109/ROBOT.1996.506562.

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- S. Kojima and M. Iwase, "Yo-yo motion control based on impulsive Luenberger Observer," 2011 50th IEEE Conference on Decision and Control and European Control Conference, Orlando, FL, USA, 2011, pp. 5323-5328, doi: 10.1109/CDC.2011.6161495.
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