PURDUE UNIVERSITY

Inverted Pendulum

Team 23

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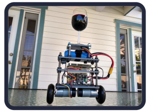
Customer Background

By continuing research in the field of controls, more opportunities for superior models are explored while offering students a rich learning experience. The ripple effects extend to benefit countless individuals in the robotics domain, furthering advancements and fostering innovation.

Self Balancing Scooters ⟺ Self Balancing Tray Tables



Problem Statement

The purpose of this project was to design and implement a multi-pendulum inverted cart system intended for educational and research use. Testing needs to be conducted to verify a stable and consistent outcome.

Requirements

Requirement	Metric
Budget	<$1000
Repeatable	5 times in a row
Quick to Balance	<15 seconds
Track Type	Rectilinear

Other Specifications:
- Documentation helpful for others to develop models
- Safety: Max allowance angle and velocity
- Stability to ensure proper pendulum angle

Experimentation and Concepts

Tuning PID Parameters

- Critical Gain (K_C)
- Period of Oscillation (P_C)
- Proportional Gain (K_P) = 0.6 * K_C
- Integral Gain (K_I) = 2 * (K_P / P_C)
- Derivative Gain (K_D) = 0.125 * K_P * P_C

1024 Pulses/Revolution: Observed a more stable and consistent output from motor but had a slower responses time in data updates.

2500 Pulses/Revolution: Faster response time, but unstable output from motor due to

Angular Acceleration Equation:

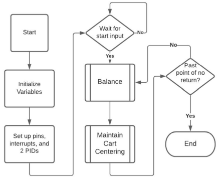
$$\ddot{\theta} = \frac{(M + m_b) \cdot g \cdot \sin(\theta) + F \cdot \cos(\theta) - m_b \cdot L \cdot \dot{\theta}^2 \cdot \sin(\theta) \cdot \cos(\theta)}{L \cdot (M + m_b \cdot \sin^2(\theta))}$$

Cart Acceleration Equation:

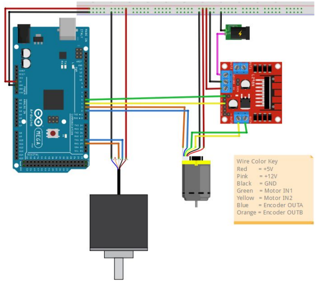
$$\ddot{x} = \frac{F + m_b \cdot \sin(\theta) \cdot (g \cdot \cos(\theta) - L \cdot \dot{\theta}^2)}{M + m_b \cdot \sin^2(\theta)}$$

PID Controller:

$$F = K_p \cdot e(t) + K_i \cdot \int_0^t e(\tau) d\tau + K_d \cdot \frac{de(t)}{dt}$$

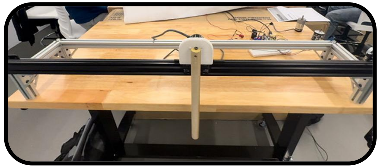


Final Design

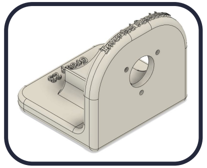


Design Goal:
Stable and operational single stage inverted pendulum, that fits within specified requirements.

Design Specifications:
- Frame: 80/20 Aluminum Bar
- E2-CWZ6VC Rotary Encoder
- 3D Printed Encoder Mount on Cart
- Powered by 37D 12V Motor
- Uses Belt Drive System
- Arduino Controller and H-bridge

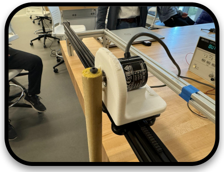


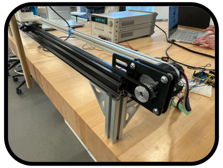
Final PID Values	
P	4.57
I	0.01
D	0.35



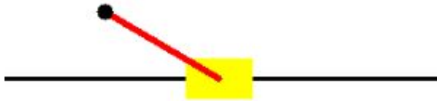
Testing

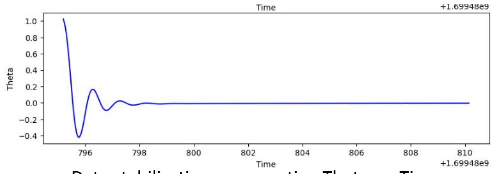
Actions Taken
- Different encoder and motor specifications tested to see effect on output.
- Calculation of PID parameters based on setup
- Rerouting 5V power from Arduino to H-Bridge
- Arduino shutdown during code upload resolved using Enable on H-Bridge.





PID control and testing were major points of emphasis in final testing. These issues were addressed by tweaking PID parameters and troubleshooting voltage fluctuations. The overall goal was to overcome challenges and validate project concept selection through continued research and experimentation.





Data stabilization representing Theta vs. Time