Team 21

Single, Double, and Triple Inverted Pendulum

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Project Description

This project's purpose is to use the existing structure of the cart and pendulum, and implement the functionality of the single, double, and triple inverted pendulum through software development and various tests. This will impact the School of Engineering Technology (SOET) in which this model will give a better understanding of the relationship between dynamics and control systems.

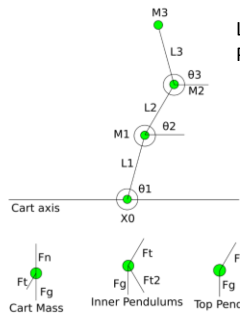
Problem Statement / Scope of Work

In the study of chaos theory, single, double, and triple pendulums can vary in their movement patters from extremely slight differences in initial state. The project involves designing and building an inverted pendulum model that can balance single, double, and triple inverted pendulums. Working with a triple inverted pendulum, the usage for it could be helpful for the human posture specifically due to the number of skeletal points that connect in a way akin to the triple inverted pendulum. The approach that we will be using will consist of a purely engineering angle. Keeping the balance of this triple inverted pendulum will be tested by sending the pendulum in a back-and-forth motion with the intent on balancing them all and reducing the amount of sway that each segment experiences.

Requirements

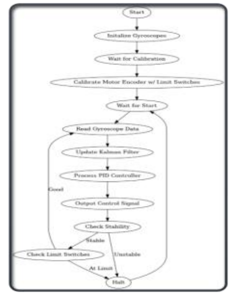
REQUIREMENT NUMBER	DESIGN REQUIREMENTS	DESIGN TARGETS	Validation
	RATIONAL		
1	Pendulum arms should be long enough for our equipment, but not too long to be handleable.	12" arm +/- 6", must be equal length.	Measurement
	Each piece needs to be able to be easily handled so the testing can be conducted in a smooth manner.		
2	Pendulum arms must be balanced.	All arms must not have a moment of inertia that will cause a large amount of angular velocity.	Calculating Moment of Inertia
	The project focuses on balancing pendulum arms in a vertical manner, so each arm must be designed to be able to balance in a vertical state. If there is little moment of inertia, then the pendulum arms will balance in equilibrium.		
3	Must balance for a prolonged time period.	2 Minutes of equilibrium.	Stopwatch during prototyping.
	It would be very simple to have the pendulum in momentary equilibrium, but the problem statement for the project calls for a mechanism that automates the balancing of the arms.		

Experimentation and Concepts



Left: Free Body Diagram of Triple Pendulum

Right: Flow Chart for Coding the Software

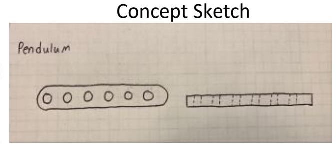


Below: Equations of Motion Output from Eom Solver

$$\frac{Lm_1\sin(\theta_1(t))\left(\frac{d}{dt}\theta_1(t)\right)^2-\frac{gm_1\sin(2\theta_1(t))}{2}+F_c(t)}{m_1\sin^2(\theta_1(t))+m_c} \quad (1)$$

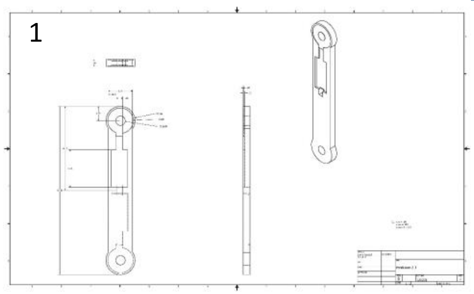
$$\frac{-\frac{Lm_1\sin(2\theta_1(t))\left(\frac{d}{dt}\theta_1(t)\right)^2}{2}+gm_1\sin(\theta_1(t))+gm_c\sin(\theta_1(t))-F_c(t)\cos(\theta_1(t))}{L\left(m_1\sin^2(\theta_1(t))+m_c\right)} \quad (2)$$

Below: Pendulum Design Concept Sketch



Final Design

1



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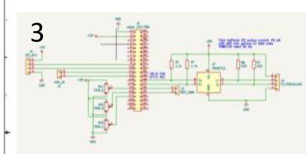

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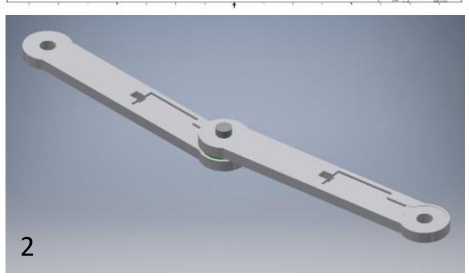

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1. Pendulum Drawing
2. CAD Rendering
3. Electrical Schematic
4. Pendulum in Real Time

FMEA

Gyroscope

Requirements	Potential Failure Mode	Potential Effect(s) of Failure	SEV	Potential Causes(s) of Failure	OCC	Current Design Controls Prevention	DET	RPN	Recommended Action(s)
The data must be accurate enough that kalman filtering allows convergence	MEMS gyroscopes out of spec	Increased error in data	4	Manufacturing error, damage during use	3	Keep gyroscope within rated specs	1	12	none
	Clock skew in gyroscope	Oscillations because of timescale mismatch	4	Temperature changes, physical stress on gyroscope oscillator	4	Switch clock source of MPU6050 from built-in oscillator to MEMS gyroscope reference	3	48	none
Connectivity with microcontroller must be uninterrupted	Wiring fault	Data not received by microcontroller	7	Physical damage, improper manufacturing	2	Visually inspect solder joints	1	14	none
	Excess noise	Invalid data read or fail to read	6	External EMI, EMI local to system	2	Use sufficiently strong pull-up resistors for wire length, have EMI shunt capacitors on data lines	3	36	none

Pendulum Arm

Requirements	Potential Failure Mode	Potential Effect(s) of Failure	SEV	Potential Causes(s) of Failure	OCC	Current Design Controls Prevention	DET	RPN	Recommended Action(s)
The structure must maintain rigidity to avoid deviating from the behavior of an ideal pendulum	Manufacturing process produces part with insufficient strength	The system may not be able to fully converge on stability due to oscillations induced by a weaker pendulum section	6	Bad filament or insufficient infill	3	Double-check settings of 3d printer before manufacturing	4	72	Develop standard procedure and checklist for additive manufacturing
	Part warps or otherwise changes shape	The data received by the sensors may be inaccurate due to offset, leading to drift during stabilization or oscillations/hunting	6	Bed misalignment, bad material choice	3	Ensure safe 3d printer operation	2	36	None required
	Part suffers complete mechanical failure	System failure and unconstrained pendulum in flight	9	Mishandling part or hard impact during testing	2	Avoid running the system in situations where the pendulum circle is partially obstructed	2	36	None required
The pendulum elements must be able to rotate freely between each other with no interference and as little resistance as possible	Shaft collar comes loose	Pendulum assembly could slide past the end of the shaft and come free of the structure	9	Vibration while running or wear over time	4	Ensure that shaft collars are tightened properly during assembly	5	180	Use thread locking compound on shaft collar
	Shaft assembly binding	Angular friction would introduce a significant amount of error between the device and the models	7	Overtightening of shaft assembly	2	After shaft assembly is put together, test to make sure pendulums swing freely	2	28	None required
	Bearing failure	Angular friction as per above, and potentially play in non-axial directions	8	Bearing wear over time	2	None	4	64	Develop scheule for bearing maintainence (grease, replacement)

Testing

Step	Test	Details	Outcome
1	LPC1768 microcontroller	The LPC1768 microcontroller will be tested with a test program that will output a 0.5 second PWM signal. This signal can be verified with a digital multimeter. This will verify the basic functionality of the microcontroller and the microcontroller I/O pins.	Success
2	Voltage Regulator Board	To verify functionality of the logic level voltage regulator circuit, the 12V power supply will be connected to the appropriate 12V input of the circuit. Then the output voltage will be measured. The expected value is 5V-6V DC. Additionally, when the circuit is powered, the red power indicator LED should illuminate.	Success
3	DC Motor Controller	To verify the motor controller a 0.5 second PWM test signal will be sent to the PWM input pins of the motor controller board. The output pin should have the same signal but at a higher power level.	Success
4	DC Motor	The DC motor will be tested by connecting the motor to the output of the motor controller and applying the PWM test signal to the motor controller. If the motor is functioning properly, it should move when the PWM signal is applied.	Success
5	Pendulum Arms	The pendulum arms will be tested for clearance and full rotation by putting together the entire assembly and rotating each individual pendulum arm around its axis of rotation, ensuring that each arm can complete a rotation without contacting another pendulum arm.	In Progress