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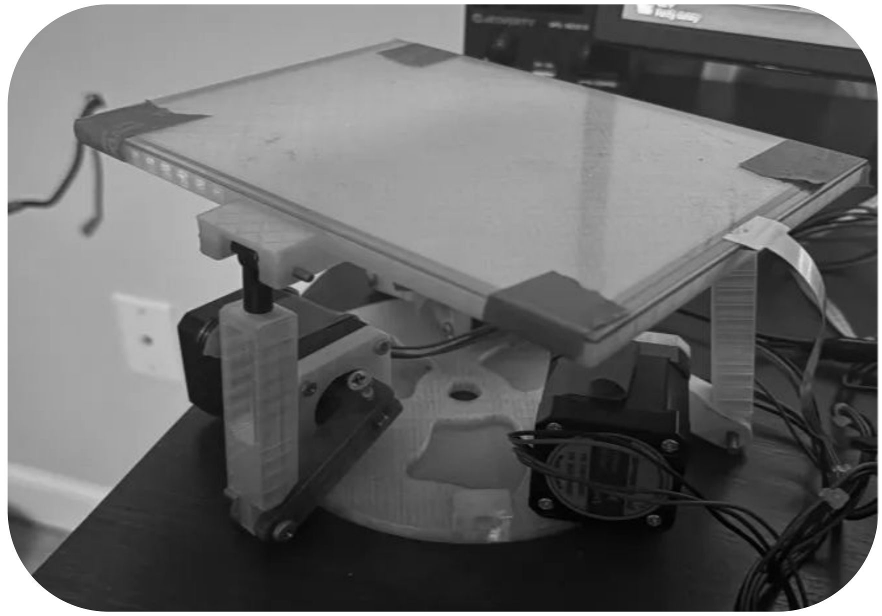
Project 1

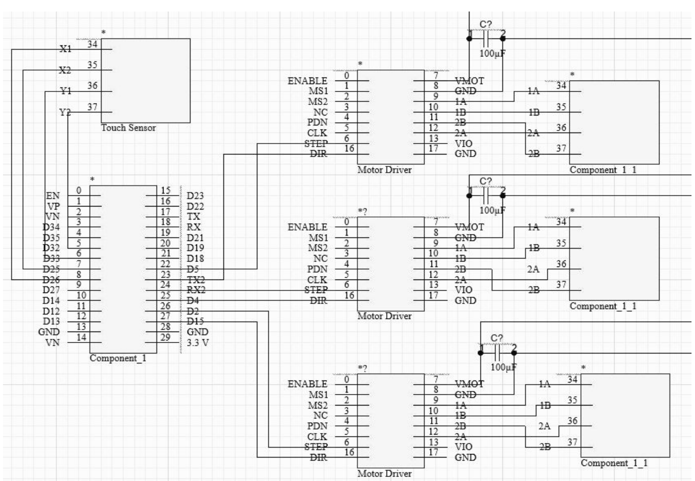
3RRS PARALLEL MANIPULATOR BALL BALANCER



The 3-RRS Parallel Manipulator Ball Balancer is a versatile robotics platform with precise motion control, ideal for studying kinematics, stabilization, and sensors in education and research. Its compact, scalable design also enables industrial applications like vibration isolation and automated sorting.

Set Up Information

Revolute to Revolute Joint (L1)	Revolute to Spherical Joint (L2)	Top Distance From Center (T1)	Bottom Distance From Center (T2)	Height from center bottom to center Top (H)
44.5 mm	98.2 mm	79.375 mm	51.765 mm	110 mm



The system incorporates an ESP32 microcontroller, a touchpad sensor, three stepper motors with corresponding TMC2208 drivers, and three 10µF capacitors, all interconnected as illustrated in the circuit diagram. The limb lengths and connection point distances are specified in the accompanying chart. The selected height was optimized to maximize the platform's range of motion while maintaining structural stability.

Inverse Kinematics

$$\begin{aligned} AX+BY+C(Z-H) &= 0 \\ \sqrt{X^2+Y^2+(Z-H)^2} &= T \\ X &= 0 \end{aligned}$$

$$\begin{aligned} AX+BY+C(Z-H) &= 0 \\ \sqrt{X^2+Y^2+(Z-H)^2} &= T \\ X &= Y\sqrt{3} \end{aligned}$$

$$\begin{aligned} AX+BY+C(Z-H) &= 0 \\ \sqrt{X^2+Y^2+(Z-H)^2} &= T \\ X &= -Y\sqrt{3} \end{aligned}$$

Turns into coordinates for top platforms

$$\begin{aligned} X &= 0 \\ Y &= -\sqrt{T^2-(H-Z)^2} \\ Z &= \frac{(T*B)}{\sqrt{C+B^2}}+H \end{aligned}$$

$$\begin{aligned} X &= Y\sqrt{3} \\ Y &= \frac{CT}{\sqrt{4C^2+(A\sqrt{3}+B)^2}} \\ Z &= \frac{-T(A\sqrt{3}+B)}{\sqrt{4C^2+\left(A\sqrt{3}+B\right)^2}}+H \end{aligned}$$

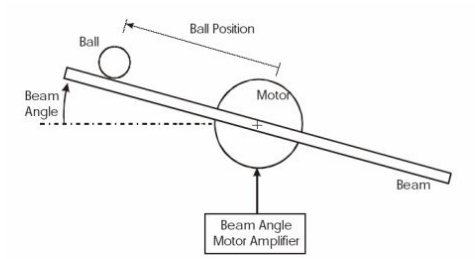
$$\begin{aligned} X &= -Y\sqrt{3} \\ Y &= \frac{CT}{\sqrt{4C^2+(-A\sqrt{3}+B)^2}} \\ Z &= \frac{-T(-A\sqrt{3}+B)}{\sqrt{4C^2+\left(-A\sqrt{3}+B\right)^2}}+H \end{aligned}$$

Use these coordinates to get required angle to reach the positions

$$\begin{aligned} U &= (X, Y, Z) \\ V &= (X_{bot}, Y_{bot}, Z_{bot}) \\ G &= \text{dist }(U, V) \end{aligned}$$

$$\theta = 90-(\cos^{-1}(\frac{{L_2}^2-{L_1}^2-G^2}{-2L_1G}))+\cos^{-1}(\frac{Z}{G})$$

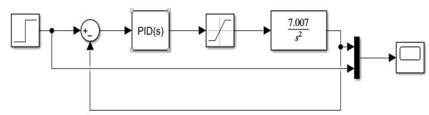
Simulation

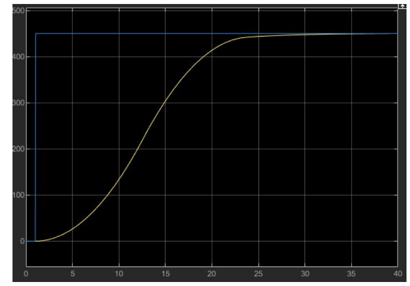


Transfer Function

$$P(s) = \frac{R(s)}{\Theta(s)} = -\frac{mg}{\left(\frac{J}{R^2}+m\right)}\frac{1}{s^2}\left[\frac{m}{rad}\right]$$

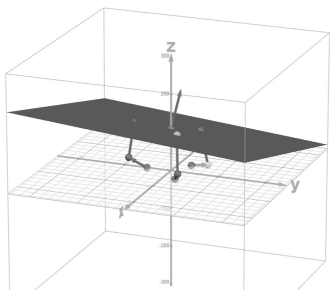
Mass of Ball (m)	Gravity (g)	Moment of Inertia (J)	Ball Radius (R)
67.35 g	-9.81m/s	0.00435 g/m^2	0.0127m





MATLAB Simulation of Ball Position on Y axis

Due to the project having 3 motors it's difficult to do a mathematical model, however we can use the system above since it is similar to what the PM is trying to achieve.



Desmos Parallel Manipulator Model

I developed a kinematic model in Desmos that visually simulates the limb movements and their resulting effects on the platform orientation, with adjustable slope parameters for both X/Z and Y/Z axes.

Coding and Improvements

The parallel manipulator's control system was programmed in C++ using the Arduino IDE. The implementation incorporates the inverse kinematic equations (detailed in Section X) along with a basic PID control algorithm for precise positioning. To ensure synchronized movement of all three motors, the system utilizes the AccelStepper library, which enables coordinated motion and simultaneous arrival at target positions.

The results seems to be good however it can be improve to more closely resemble the simulation results if we made the motors move slower when the ball is near the motor. This would help achieve critical state.

Results