MECHANICAL ENGINEERING
UTAH VALLEY UNIVERSITY

PING PONG ROBOT

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Purpose:

Design and program a 5-axis gantry robot to play ping pong automatically against a human.

Customer Needs:

Customer needs were cultivated through insights from user interviews and an analysis of challenges the previous team ran into. A scoring matrix was used to objectively evaluate and prioritize each need based on its significance. This allowed us to narrow down customer needs into measurable, and verifiable requirements.

Table 1: Customer needs weighted

Customer Needs	Priority	Weight	pts	Total
Difficulty selection	8	0.05	6.83	0.341667
Works w/o supervision	3	0.2	7.58	1.516667
Trash Talking/Feedback	9	0.05	6.33	0.316667
Keeping Score	7	0.07	7.58	0.530833
Returns ball consistently	1	0.3	9.79	2.9375
Quick set up	4	0.15	7.29	1.09375
Robust/durable	5	0.1	7.92	0.791667
Can hold any paddle	6	0.08	7.08	0.566667

Figure 1: Easy take down and set up

Scoring Matrix:

A Scoring Matrix was created to identify the team's main priorities for the project. Three main focuses were determined:

-Consistent Ball Returns: Enhancing the robot's ability to accurately track and swiftly move along the projected path of the ball.

-Works w/o Supervision: Implementing a push and go standalone system, such as the Jetson Orin Nano, to enable the robot to work without direct supervision.

-Quick Set Up: Quick-release hardware was explored alongside frame modifications aimed at boosting stability.

Table 2: Design requirements

Customer Needs	Function/Design Requirements	Metric	Unit
Returns ball consistently	Image Processing Time	0.1	s
	Mechanical Settling Time	0.5	s
	XYZ Paddle Coverage	6x5x1.5	ft^3
	X Speed	6	ft/s
	Y Speed	5	ft/s
	Z Speed	1.5	ft/s
	Ball return velocity	>15	ft/s
Works w/o supervision	Runs by itself after set up	Y/N	--
Keeps Score	Maintains and displays score accurately	1	point
Quick set up	Set up time	30	min
Robust/Durable	No flexing in frame	Y/N	--
Can hold any paddle	Universal paddle holder	Y/N	--

Physical Design:

Paddle Holder:

The paddle holder was designed to enable the robot to use any paddle and move in new degrees of freedom. Giving the robot the ability to twist and swing the paddle to better return balls. After brainstorming concepts and creating several prototypes, the team settled on the current design. It features a hinged tapered clamp to secure the paddle and an integrated magnet for twist detection.

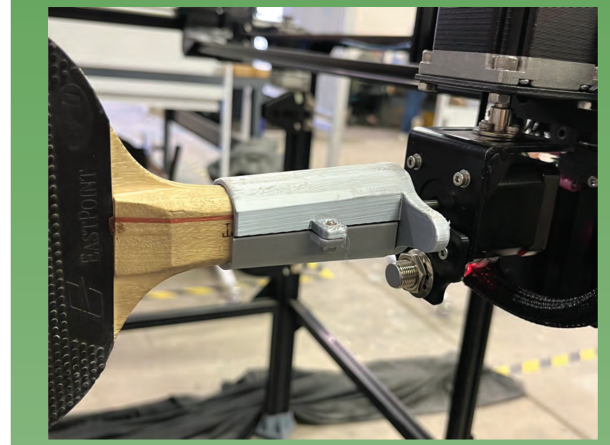

Figure 2: Paddle holder final design

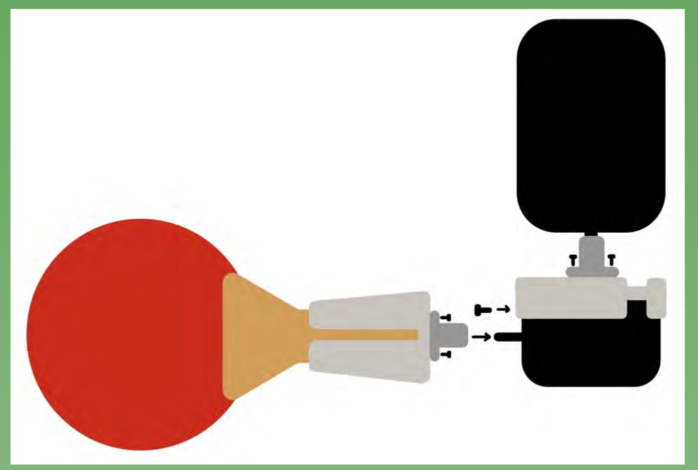

Figure 3: Swing and tilt design

Camera Stand:

Figure 4: Camera stand

The camera stand design improves the vision system of the robot by ensuring stable positioning for the ZED 2i camera. Unlike the previous tripod setup, our stand maintains a fixed position for consistent tracking. Its height allows for precise ball tracking, even at the table's edges where the view cone of the camera affects visibility. LEDs were integrated to ensure consistent lighting across different environments.

Analysis:

Stability analysis, conducted experimentally and through finite element analysis (FEA), identified areas susceptible to vibrations and in need of reinforced design elements. Both methods revealed the need for additional structural support to minimize frame deflection. The implemented structural enhancements, shown below, ensure precise and consistent paddle movements, enhancing the robot's overall performance.

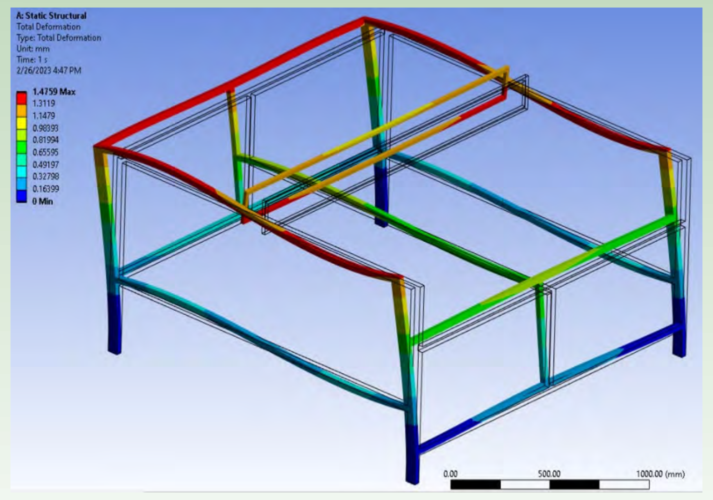

Figure 5: FEA analysis of frame stability

Figure 6: Inner support beams and weights

Software:

Ball Tracking:

The ZED 2i camera, a multicamera and sensor system, provides position and velocity data for a ping pong ball as it moves. A green bounding box visually indicates ball tracking and position accuracy. The ball detection program calculates distance from table edges and height above the playing surface, crucial for decision-making. This data informs the robot's actions, ensuring accurate responses to ball location and trajectory.

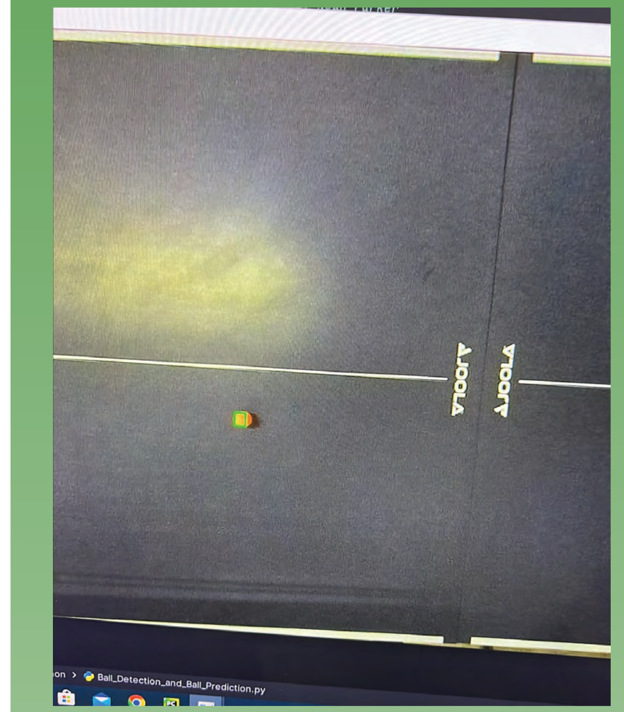

Figure 7: Bounding box live tracking

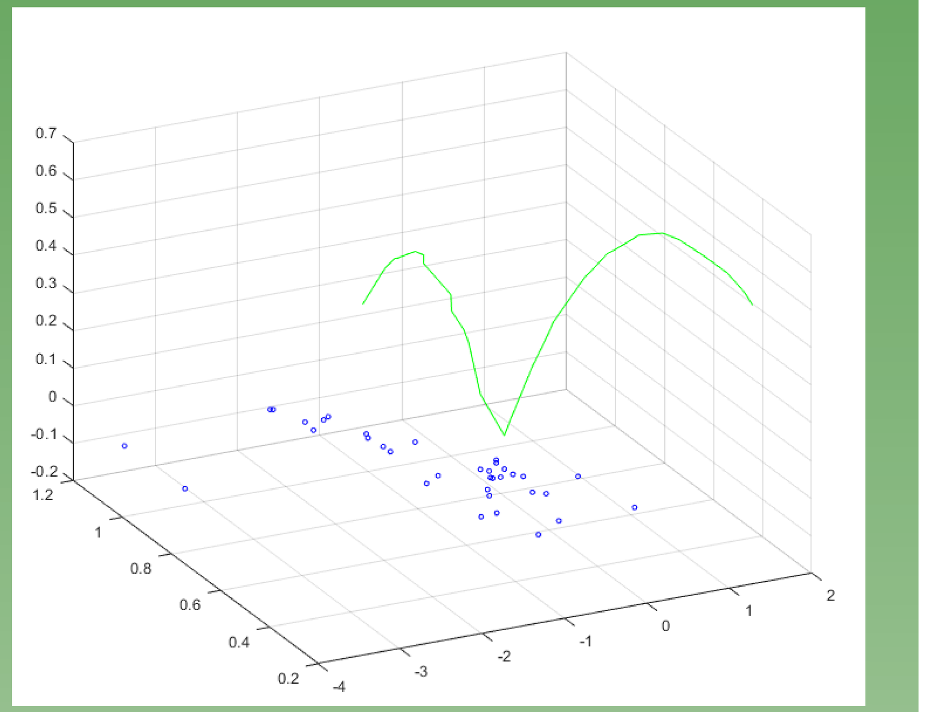

Figure 8: Trajectory calculator predicting ball bounce

Controller:

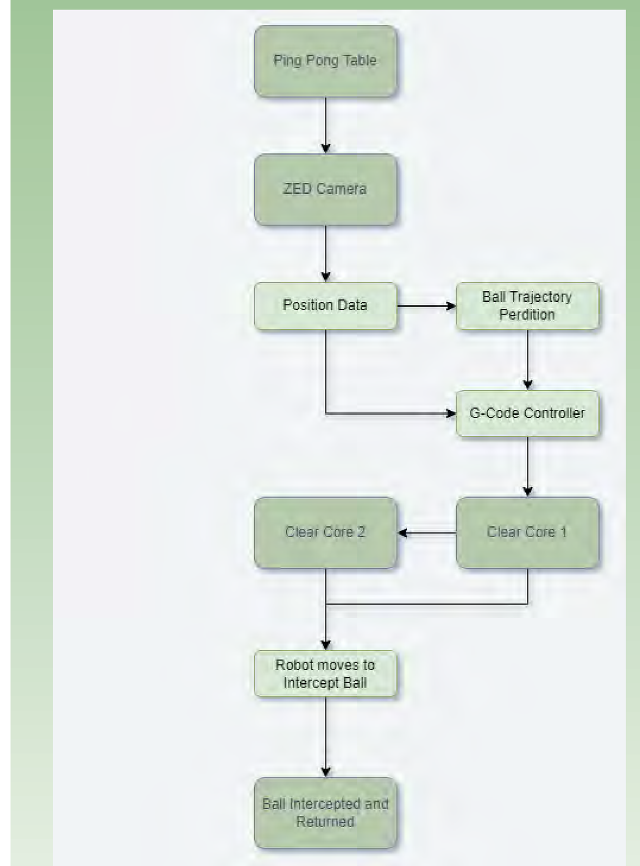

Figure 9: Coding flow chart

The robot receives position data then executes G-code commands to the ClearCore Arduinos. G-code allows us to move stepper and servo motors in inches to specific positions in the real world. The controller ensures smooth motor acceleration and deceleration to prevent robot shaking and minimize stress on structural components.

Final Design:

The final design of this project has 5-axis of freedom (X,Y,Z,Swing,Tilt). This project uses a ball detection camera to communicate with a 5-axis gantry system to consistently return a ping pong ball.

Figure 10: Ping pong robot final design