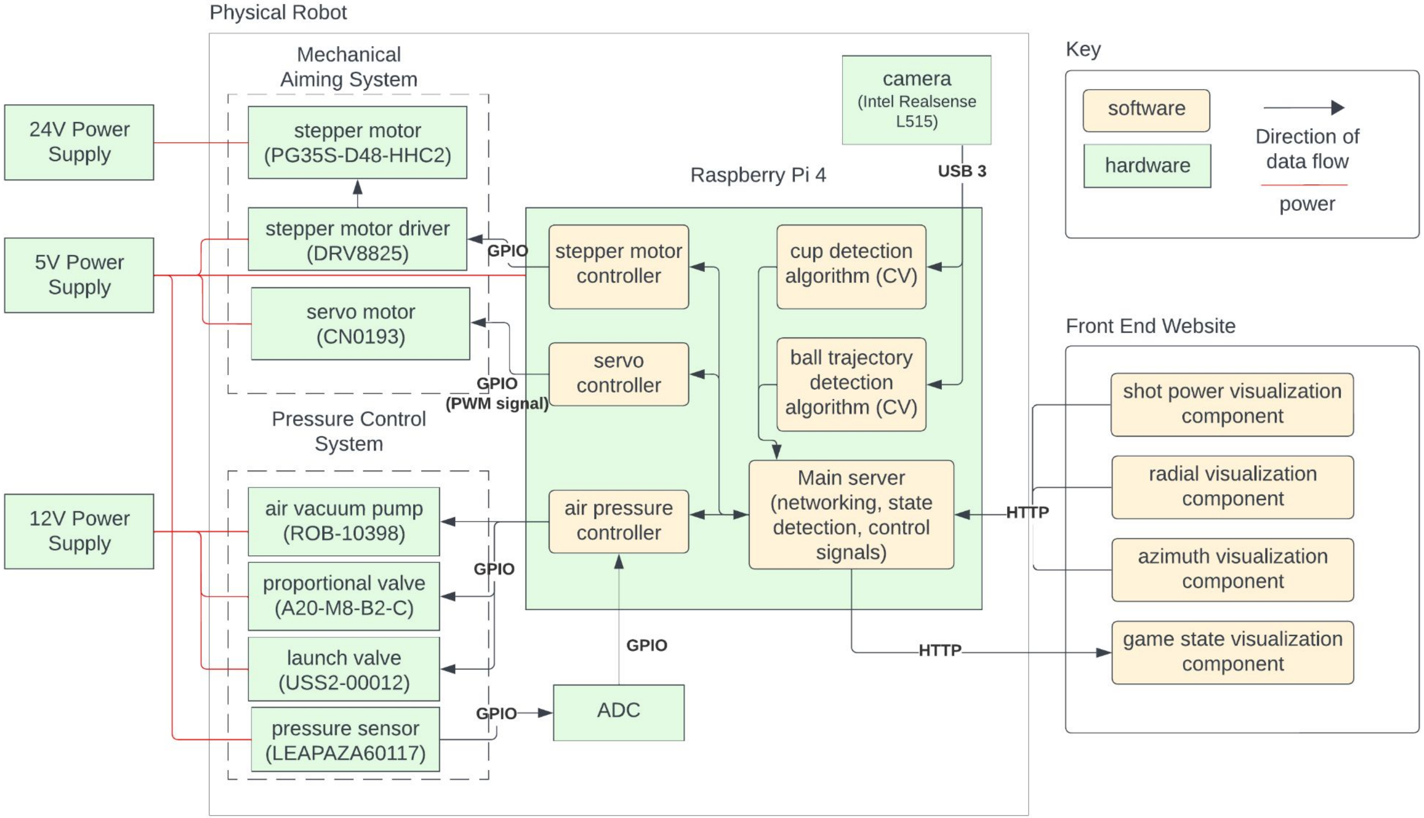
Use Case & Design Requirements

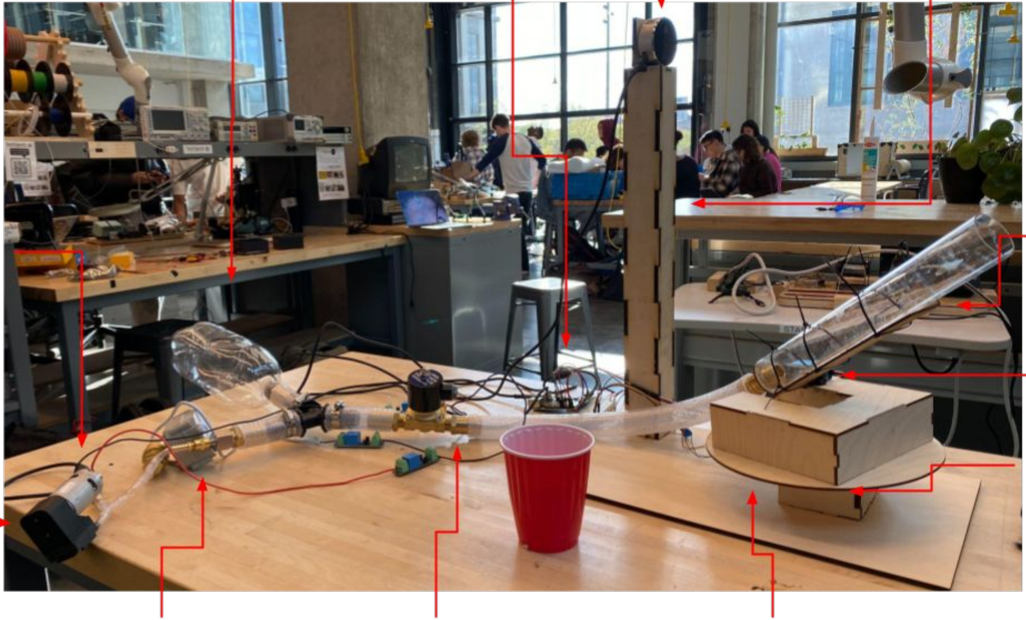
PongPal™ makes water pong more accessible by allowing one to remotely control the robot and get feedback

Requirement 1 The user should experience minimal noise under the same robot settings to maximize the skill aspect of the game (**Accuracy & Reliability**)	Aiming system's angular error < **0.5 degrees**
	Cup location detection error < **5cm**
	Ball trajectory detection error < **5cm**
	When aiming **1.5m - 3m away** and set at same setting, < **5cm depth variance and** < **2cm horizontal variance**
Requirement 2 The user should have seamless gameplay experience (**Responsiveness**)	Processing latency for cup detection and ball trajectory detection < **5s**
Requirement 3 A new user can easily set up and learn to play the game (**Accessibility**)	Average UI/UX rating (intuitiveness & enjoyment) > **8/10**

Solution Approach


Physical Robot
Mechanical Aiming System
24V Power Supply
stepper motor (PG35S-D48-HHC2)
stepper motor driver (DRV8825)
5V Power Supply
servo motor (CN0193)
GPIO
GPIO (PWM signal)
Pressure Control System
12V Power Supply
air vacuum pump (ROB-10398)
proportional valve (A20-M8-B2-C)
launch valve (USS2-00012)
pressure sensor (LEAPAZA60117)
GPIO
GPIO
ADC
GPIO
camera (Intel Realsense L515)
USB 3
Raspberry Pi 4
stepper motor controller
servo controller
air pressure controller
cup detection algorithm (CV)
ball trajectory detection algorithm (CV)
Main server (networking, state detection, control signals)
HTTP
HTTP
Key
software
hardware
Direction of data flow
power
Front End Website
shot power visualization component
radial visualization component
azimuth visualization component
game state visualization component

Complete Solution



Pressure Chamber

RPi4

L515 Lidar Camera

Camera Pole

LEPAZA60117
Pressure Sensor

ROB-10398
Air Vacuum Pump

A20-M8-B2-C
Proportional Valve

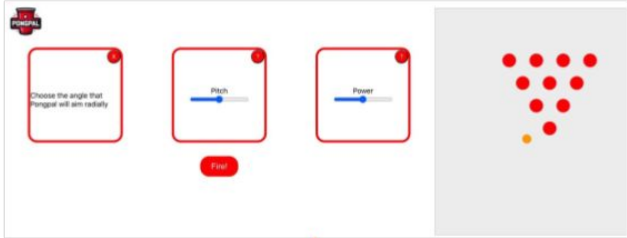
USS2-00012
Launch Valve

Lazy Susan Plate

Launch
Barrel

CN0193
Servo Motor

PG35S-D48-HHC2
Stepper Motor



Choose the angle that Pongpal will aim radially

User Interface

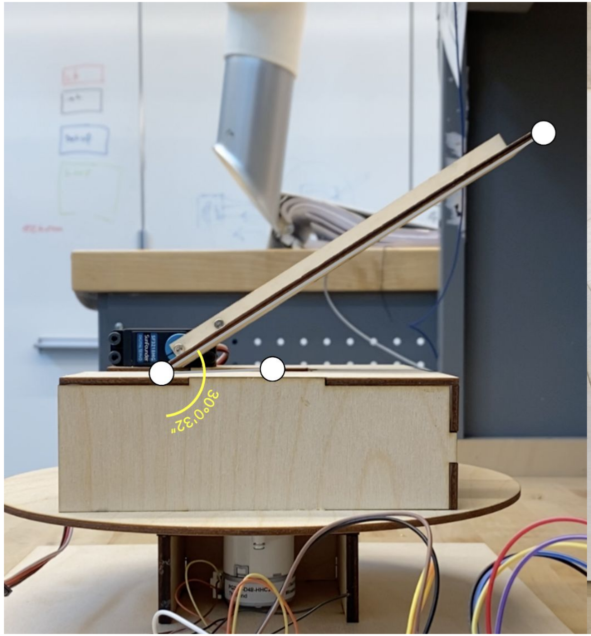
Complete Solution

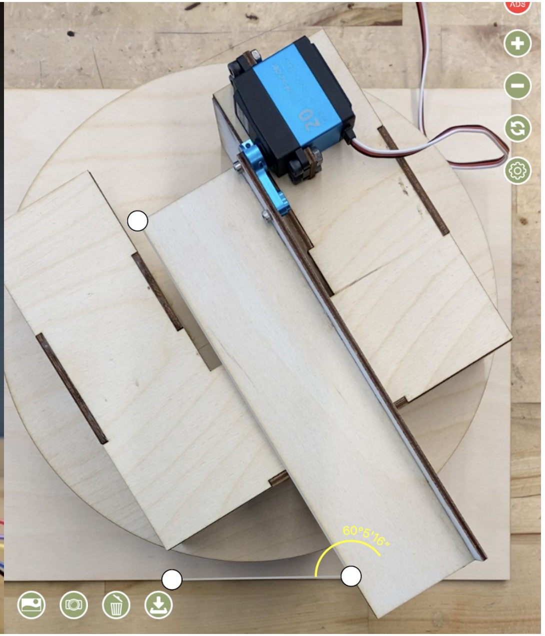
Testing Plan

Requirements	**Testing Plan**
Aiming system's angular error **< 0.5 degrees**	For both vertical and radial aiming system, set 10-degrees-apart angles in full range, and measure the average deviation
Cup location detection error **< 5cm**	Place robot and cups in a known position, and measure the cup detection's deviation and the ball landing place's deviation from ground truth 10 times
Ball trajectory detection error **< 5cm**	
When aiming **1.5m - 3m away** and set at same setting, **< 5cm depth variance and < 2cm horizontal variance**	Set the pressure level as same, perform 10 shots, then mark the landing spot
Processing latency for cup detection and ball trajectory detection **< 5s**	Measure the processing latency of cup detection and ball trajectory detection 10 times
Average UI/UX rating (intuitiveness & enjoyment) **> 8/10**	Show 10 users (5 users with pong experience, 5 randomly selected) UI and ask them to rate their experience

Verification (Aiming system)

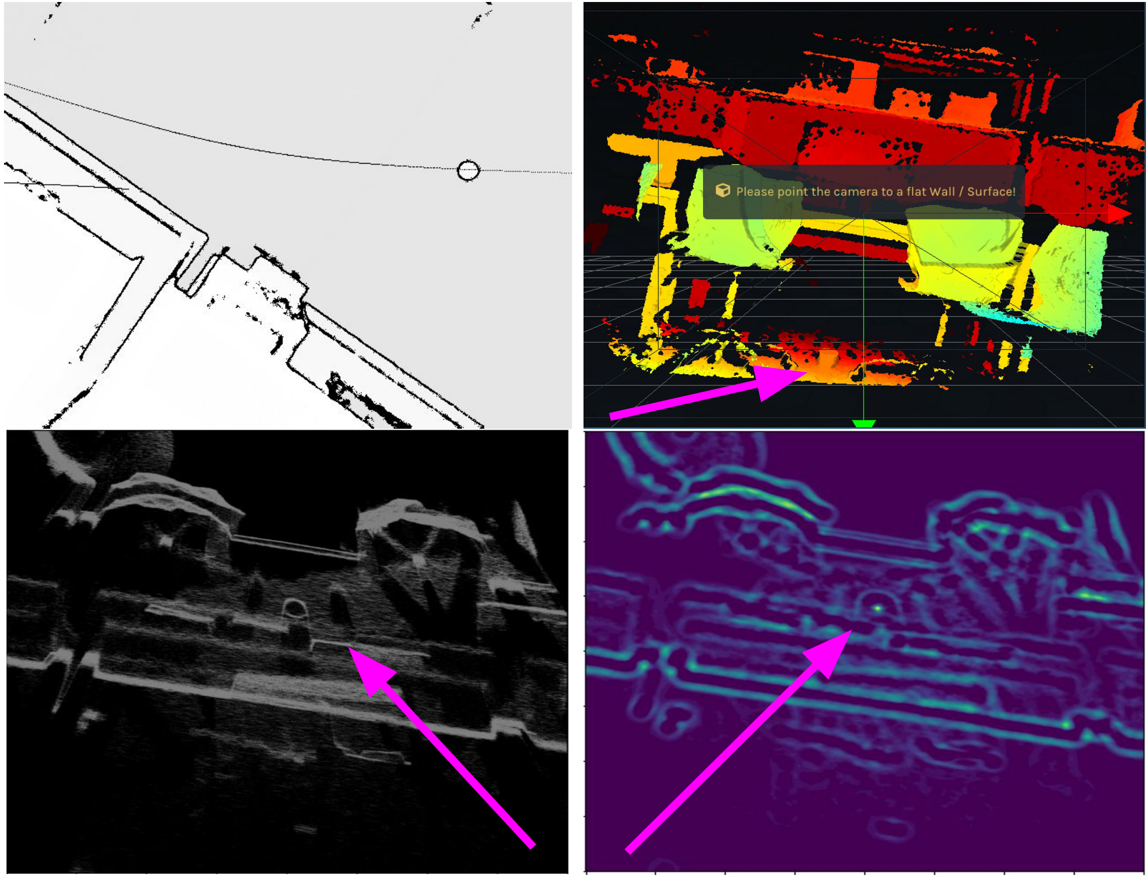
Requirements	Aiming system’s angular error < **0.5 degrees**
Testing Plan	Set 10-degrees-apart angles in full range, and measure the average deviation
Performance	Radial aiming system’s average angular error: **0.26 degrees** Vertical aiming system’s average angular error: **0.14 degrees**





Verification (CV)

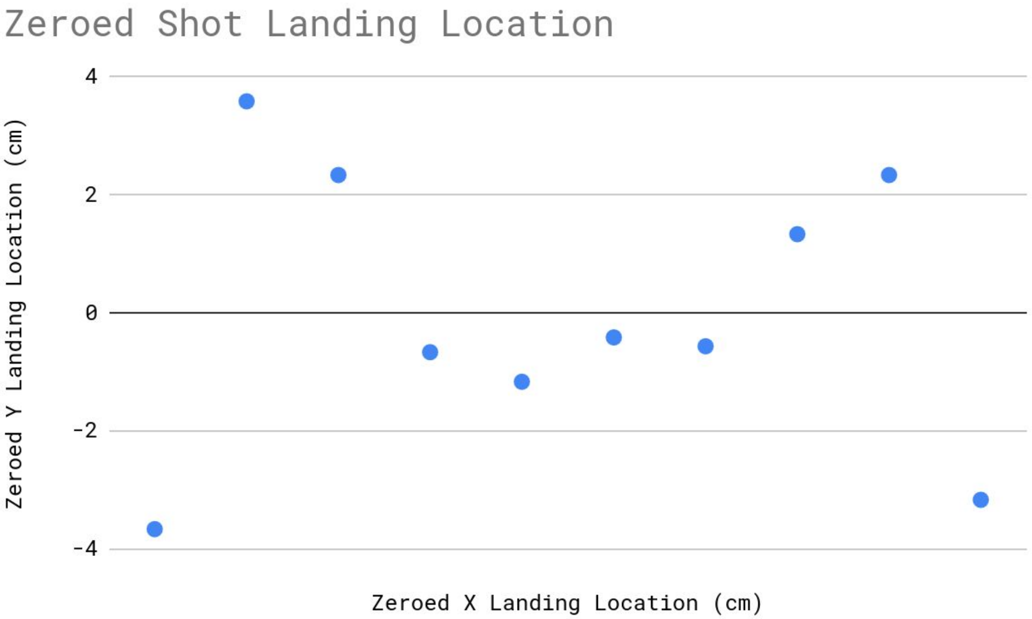
Requirements	Cup location detection error < **5cm** Ball trajectory detection error < **5cm** Processing latency for cup detection and ball trajectory detection < **5s**
Performance	Cup Detection error: **X: 0.80 cm** **Y: 0.62 cm** Ball Trajectory Error: **X: 2.45 cm** **Y: 4.289 cm** Processing latency: **4.37 seconds**



Please point the camera to a flat Wall / Surface!

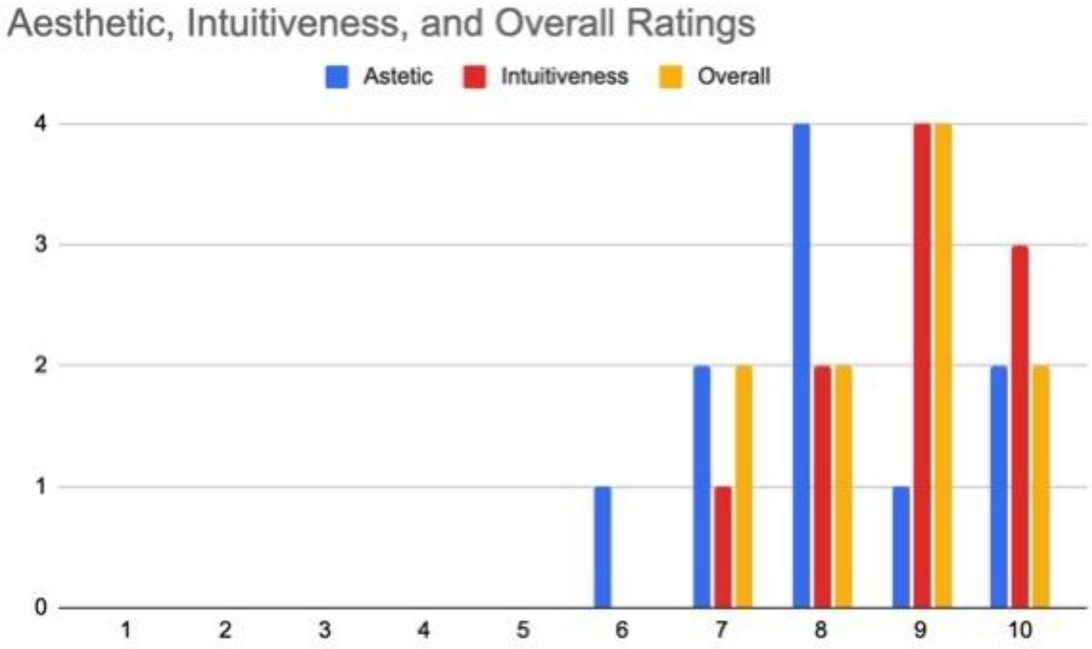
Verification (Launching System)

Requirements	When aiming **1.5m - 3m away** and set at same setting, **< 5cm depth variance and < 2cm horizontal variance**
Testing Plan	Set the pressure level as same, perform 10 shots, then mark the landing spot
Performance	Depth Variance: **5.69 cm** Horizontal Variance: **3.167 cm** Interesting note: high variance shots seemed to come in batches



Verification (UI)

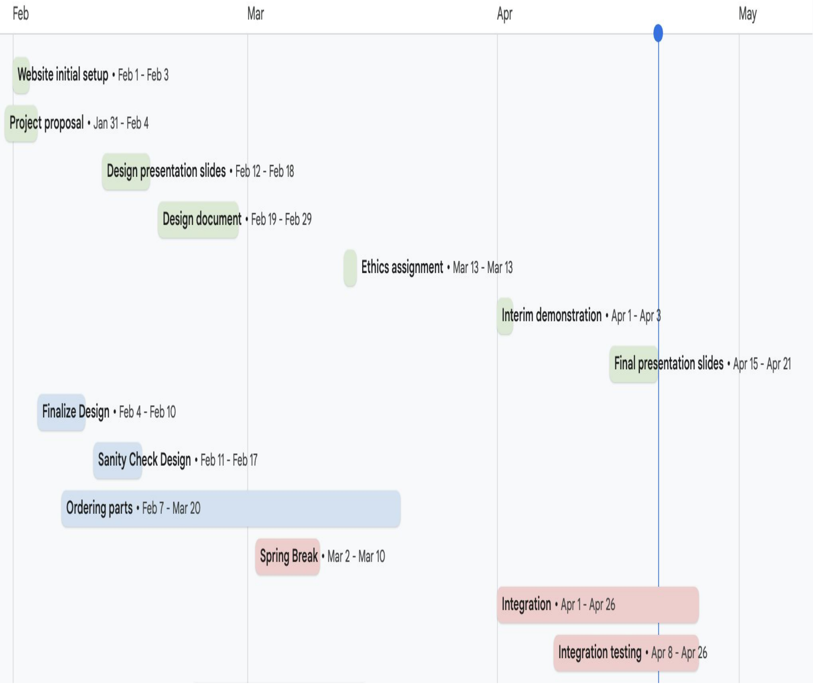
Requirements	Average UI/UX rating (intuitiveness & enjoyment) > **8/10**
Testing Plan	Show 10 users (5 users with pong experience, 5 randomly selected) UI and ask them to rate their experience
Performance	Average Aesthetics rating: **8.9** Average Intuitiveness rating: **8.9** Average overall enjoyment rating: **8.6**



Design Trade-offs

What we chose	**vs**	**What was considered**
Local Image Analysis		Remote image analysis
Dynamic DNS		Backend server
LIDAR		Camera
Servo motor for vertical aiming		Linear actuator
Pressure launching system		Mechanical launching system

Project Management



Website initial setup • Feb 1 - Feb 3

Project proposal • Jan 31 - Feb 4

Design presentation slides • Feb 12 - Feb 18

Design document • Feb 19 - Feb 29

Ethics assignment • Mar 13 - Mar 13

Interim demonstration • Apr 1 - Apr 3

Final presentation slides • Apr 15 - Apr 21

Finalize Design • Feb 4 - Feb 10

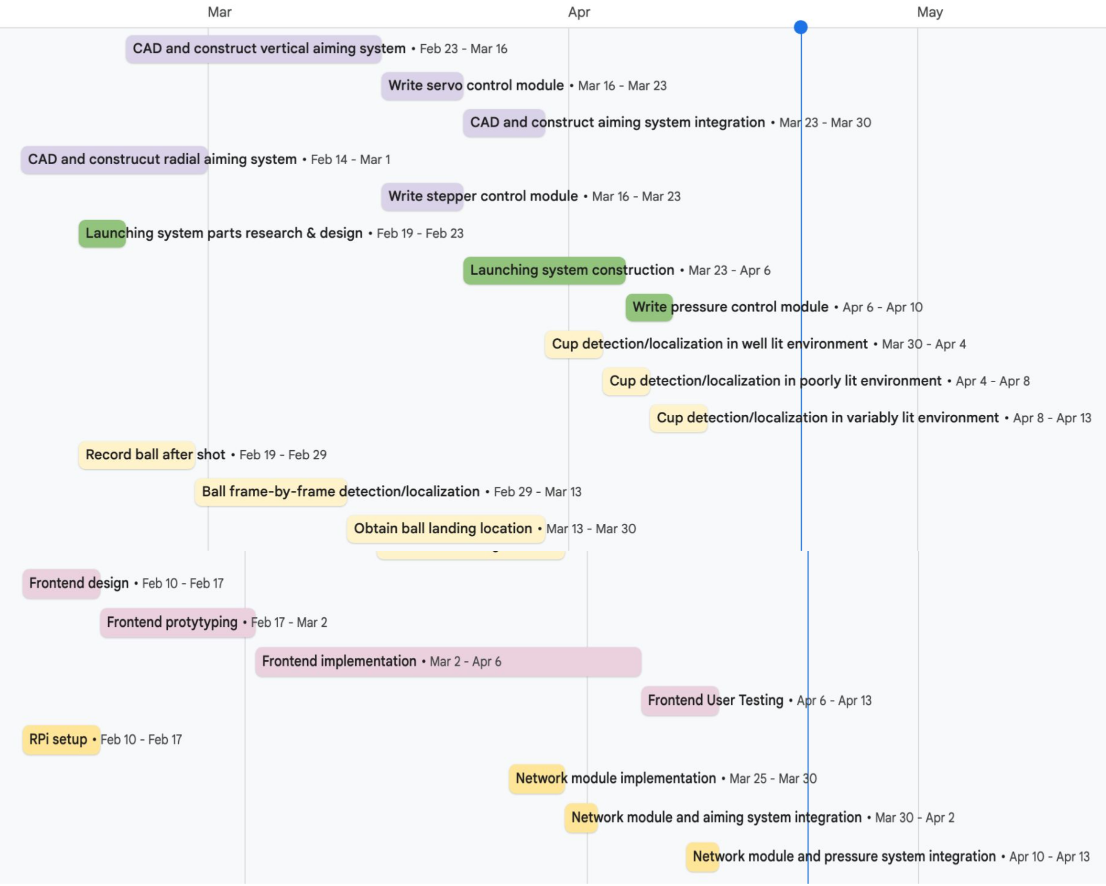
Sanity Check Design • Feb 11 - Feb 17

Ordering parts • Feb 7 - Mar 20

Spring Break • Mar 2 - Mar 10

Integration • Apr 1 - Apr 26

Integration testing • Apr 8 - Apr 26



CAD and construct vertical aiming system • Feb 23 - Mar 16

Write servo control module • Mar 16 - Mar 23

CAD and construct aiming system integration • Mar 23 - Mar 30

CAD and construcut radial aiming system • Feb 14 - Mar 1

Write stepper control module • Mar 16 - Mar 23

Launching system parts research & design • Feb 19 - Feb 23

Launching system construction • Mar 23 - Apr 6

Write pressure control module • Apr 6 - Apr 10

Cup detection/localization in well lit environment • Mar 30 - Apr 4

Cup detection/localization in poorly lit environment • Apr 4 - Apr 8

Cup detection/localization in variably lit environment • Apr 8 - Apr 13

Record ball after shot • Feb 19 - Feb 29

Ball frame-by-frame detection/localization • Feb 29 - Mar 13

Obtain ball landing location • Mar 13 - Mar 30

Frontend design • Feb 10 - Feb 17

Frontend protytyping • Feb 17 - Mar 2

Frontend implementation • Mar 2 - Apr 6

Frontend User Testing • Apr 6 - Apr 13

RPi setup • Feb 10 - Feb 17

Network module implementation • Mar 25 - Mar 30

Network module and aiming system integration • Mar 30 - Apr 2

Network module and pressure system integration • Apr 10 - Apr 13

🟩 : Deliverable
🟦 : Design General
🟥 : General

🟪 : Aiming Systems (Seung Yun)
🟩 : Pressure (Alex)
🟨 : Detection (Alex)

🟪 : Frontend/Interface (Mike)
🟨 : Backend (Seung Yun)

Conclusion

Lessons learned

- Designing a mechanically solid robot is hard
- Computer vision is hard
- Precise pressure control is hard
- Simple and Intuitive UI is hard
- Balancing budget constraint vs quick iteration

What’s left to do

- Integrate CV results into frontend UI
- Integrate pressure system into frontend UI
- Integration testing