Capstone Project Final Presentation

August 7, 2018

Electronic Systems Engineering (B.Eng)

Conestoga College - Class of 2018

Team

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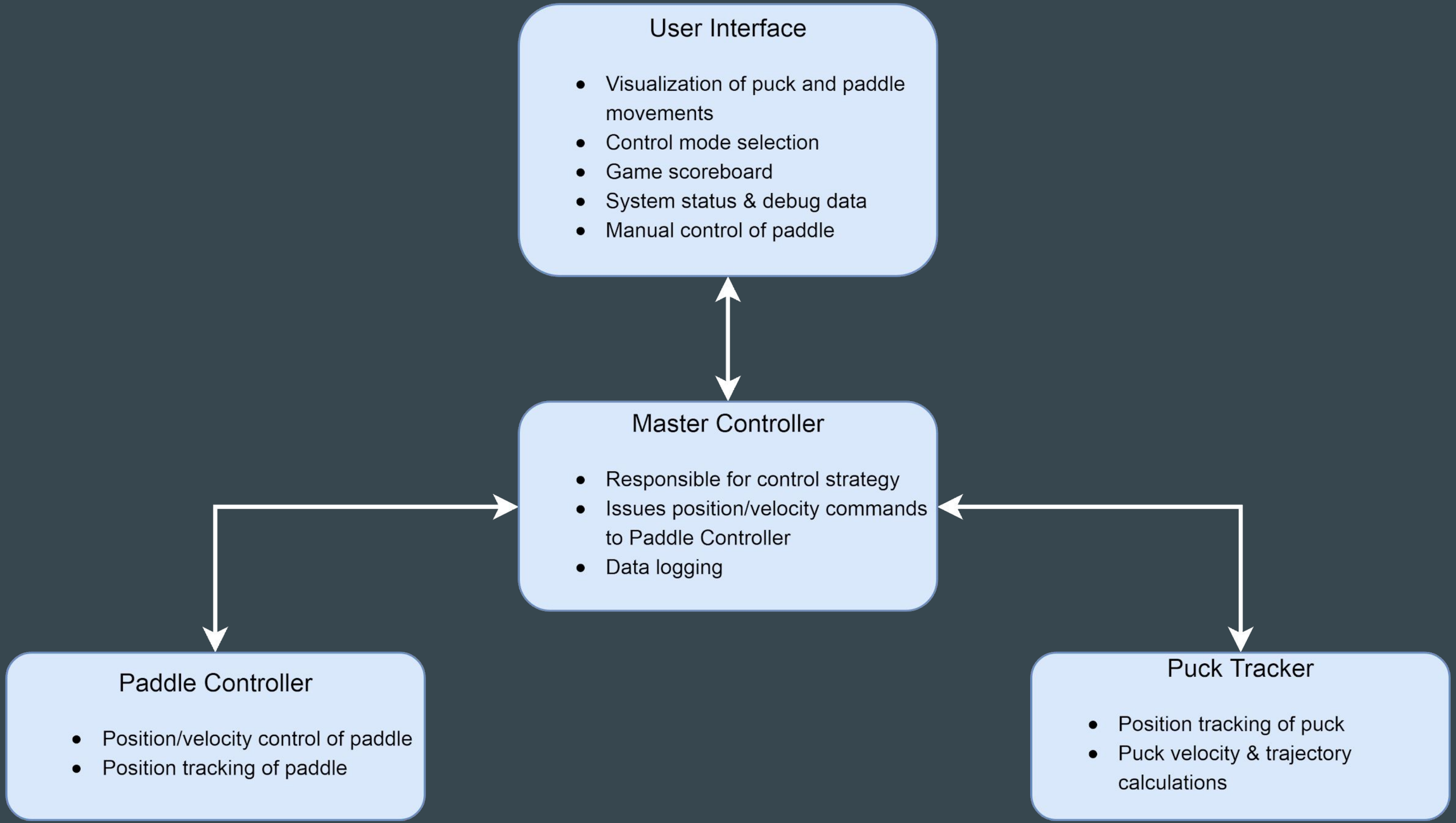
Overview

1. Review Project Proposal
2. Project Status
3. Future Development
4. Demonstration
5. Q&A

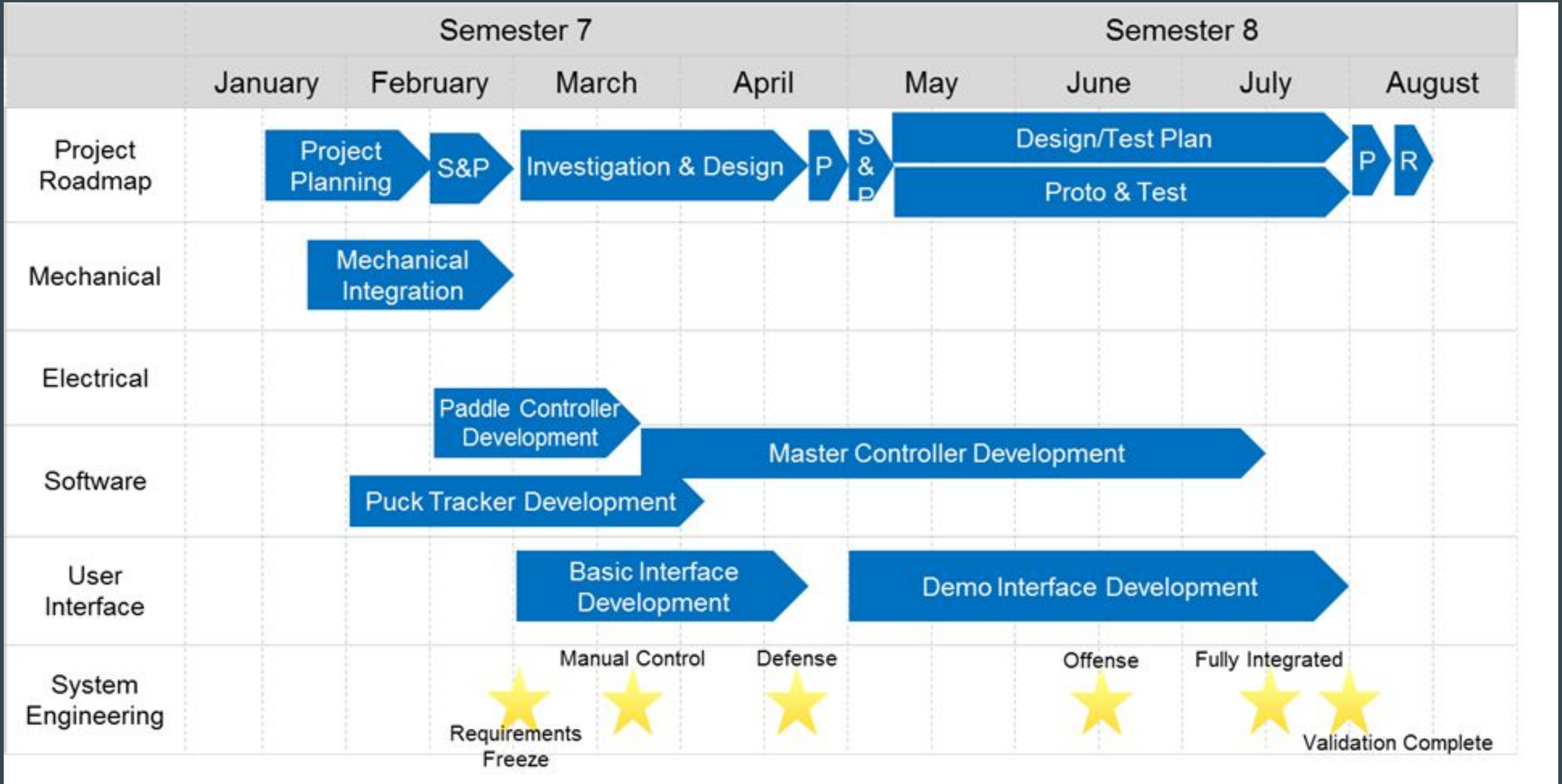
Project Proposal

Project objective:
Develop a robotic system capable of playing air hockey against a human player.

Air Hockey Robot Block Diagram - Proposal

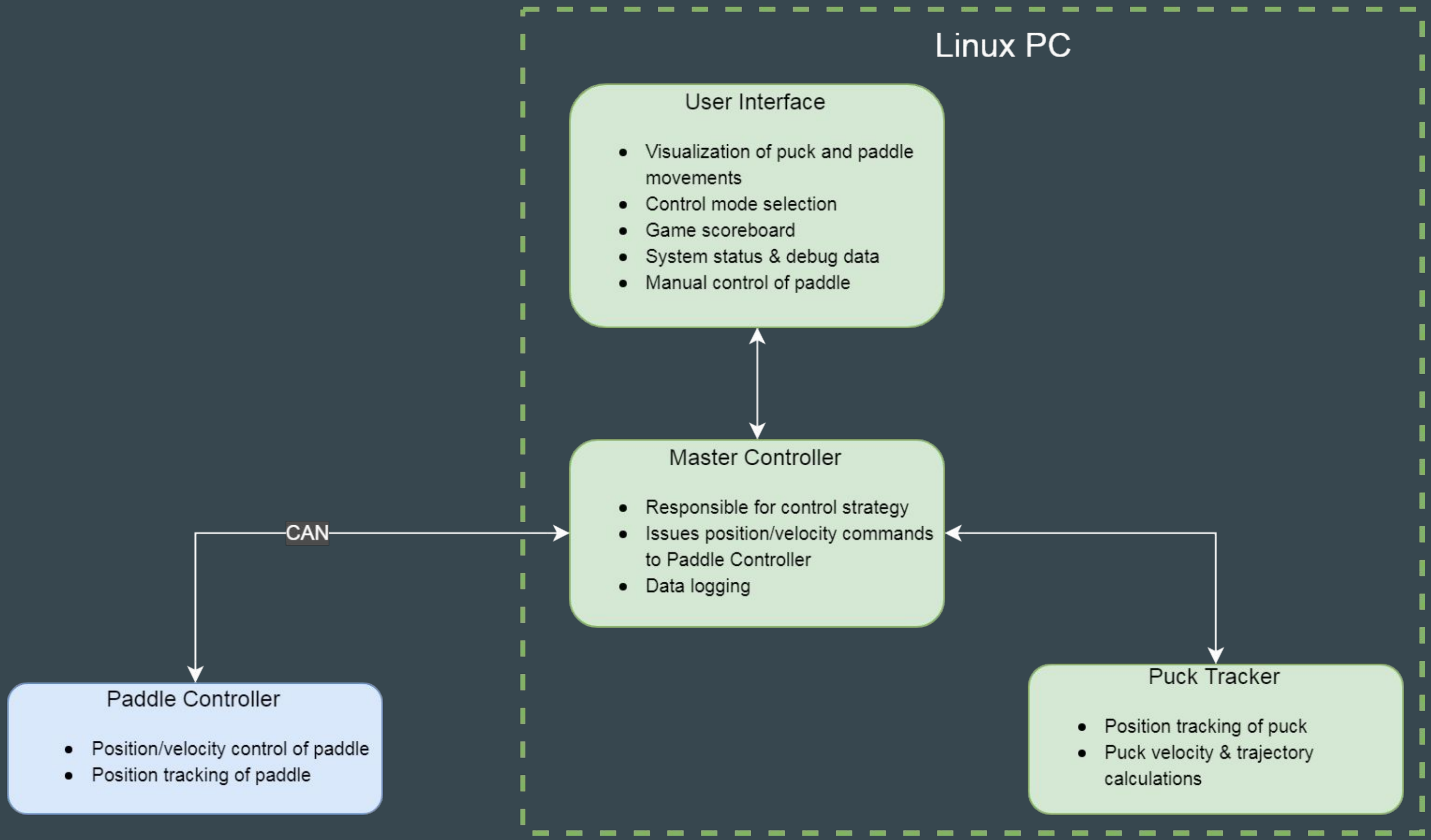


Project Plan



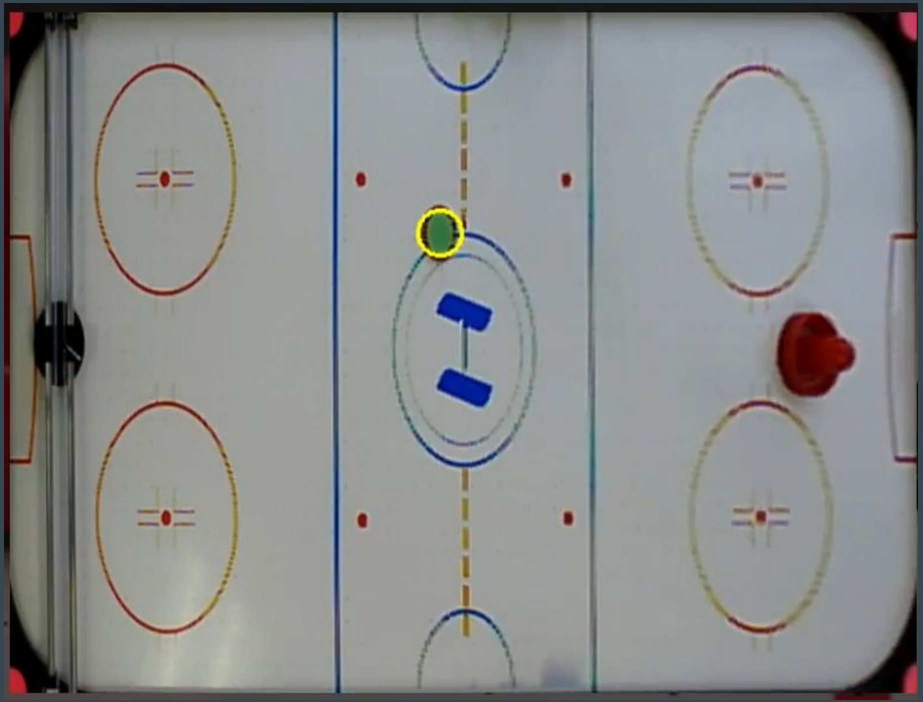
Project Status

Project Status - Puck Tracker



Puck Tracker Implementation

- Vision based position tracking with OpenCV
  - Investigated alternatives (Magnets, Ultrasonic Sensors, etc.)
- Key attributes for puck detection
  - Color
  - Area
  - Radius



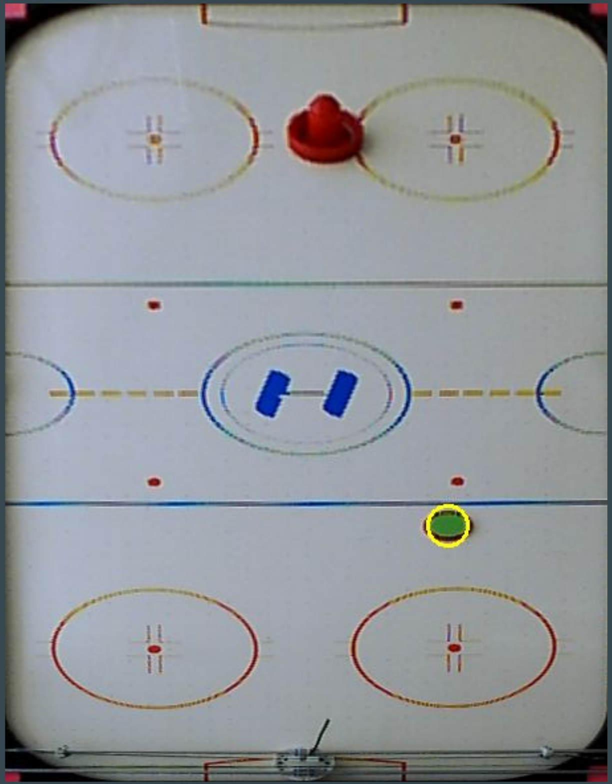
Puck Localization & Perspective Correction

Goal

- Provide a “top down” view for consistent relative position detection
- Frame the playing surface

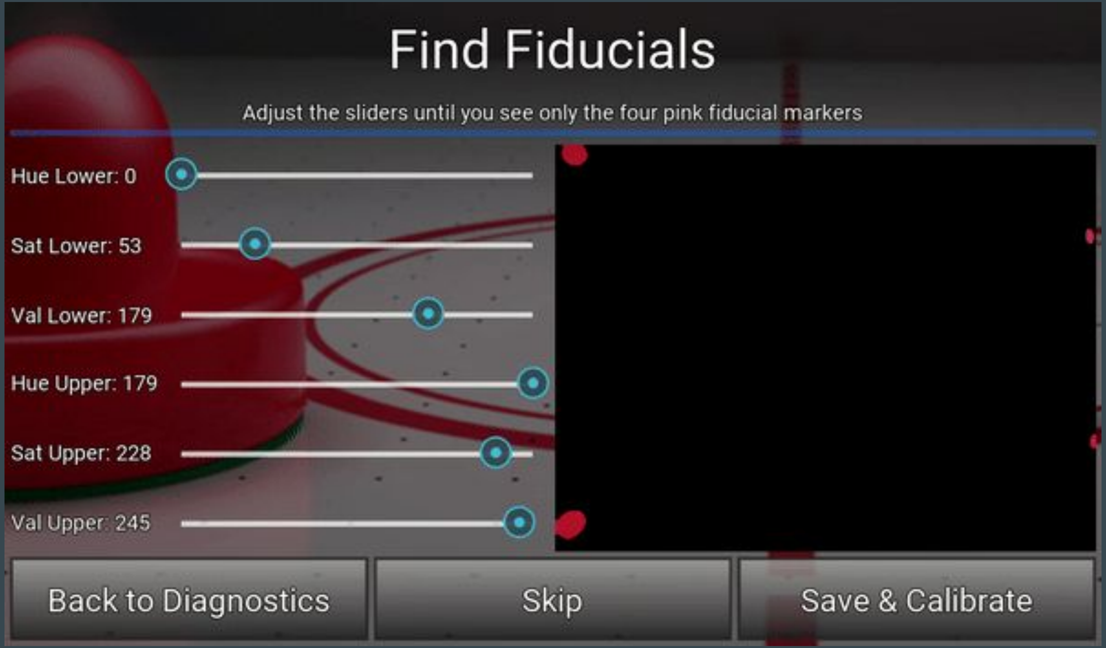
Methodology

- Identify 4 fiducials
- Calculate transformation matrix
- Warp image perspective
- Apply pixel to mm scaling factors for puck position
- Puck velocity = distance/time

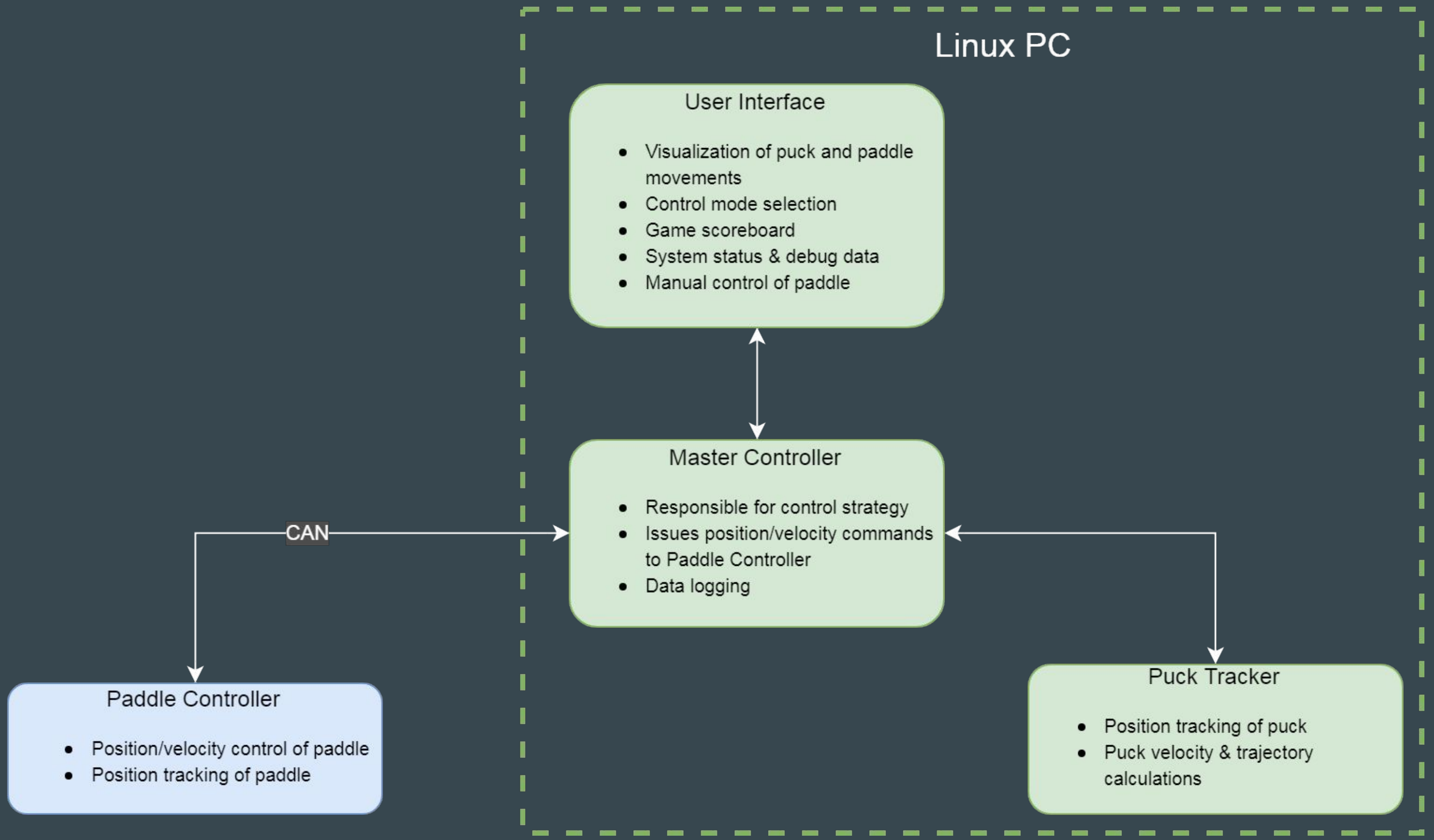


Adjusting for Varying Lighting Conditions

- Ability to calibrate the computer vision system using UI sliders
- Values saved to JSON file



Project Status - Paddle Controller



Paddle Controller High-Level Requirements

1. Accelerate the paddle to human-level speeds
2. Control paddle position to +/-5mm in two dimensions
3. Operate safely at high speeds in close proximity to humans

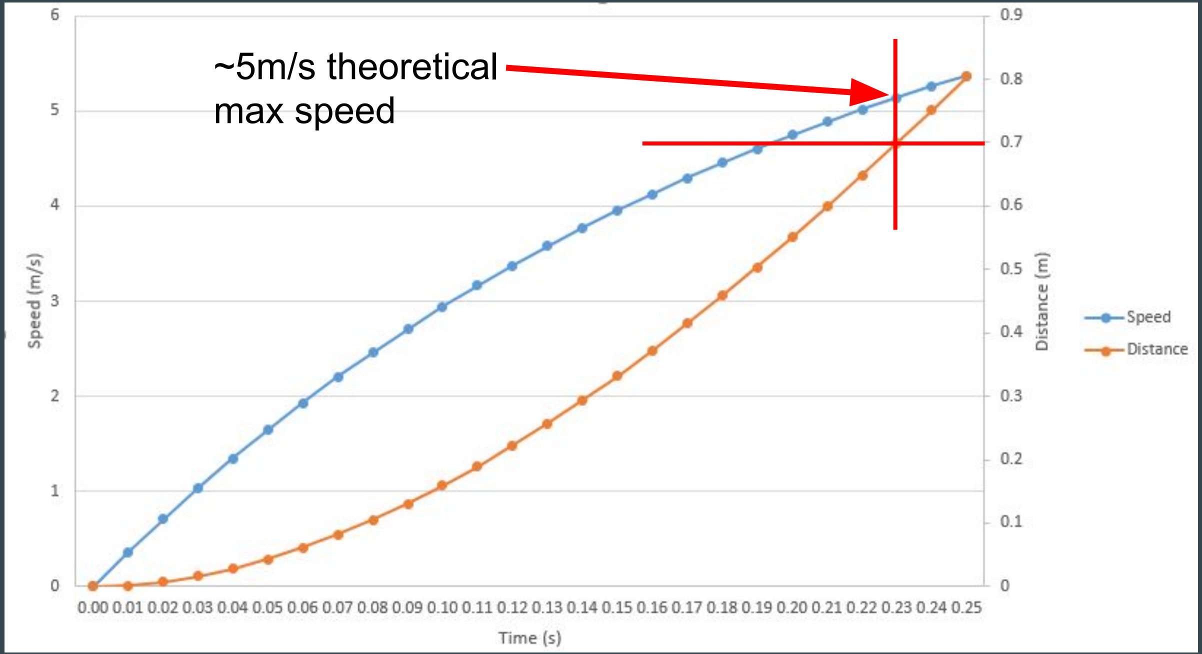
System Modelling

Modelled system performance as a function of individual component parameters.

Real-world data from low-speed prototype used to accurately estimate static and dynamic friction.

Model of high-speed system accurate to within 20%.

Step Response for High-Speed Prototype



$$v(t) = \left(\frac{d\,f}{2\,S} - \frac{q}{S}\right)e^{-\frac{4\,S\,t}{d\,m}} - \frac{d\,f}{2\,S} + \frac{q}{S}$$

Linear Speed vs Time

$$\int\left(\left(\frac{d\,f}{2\,S} - \frac{q}{S}\right)e^{-\frac{4\,S\,t}{d\,m}} - \frac{d\,f}{2\,S} + \frac{q}{S}\right)dt = -\frac{(d\,f - 2\,q)\left(d\,m\,e^{-\frac{4\,S\,t}{d\,m}} + 4\,S\,t\right)}{8\,S^2} + \text{constant}$$

Distance Travelled vs Time

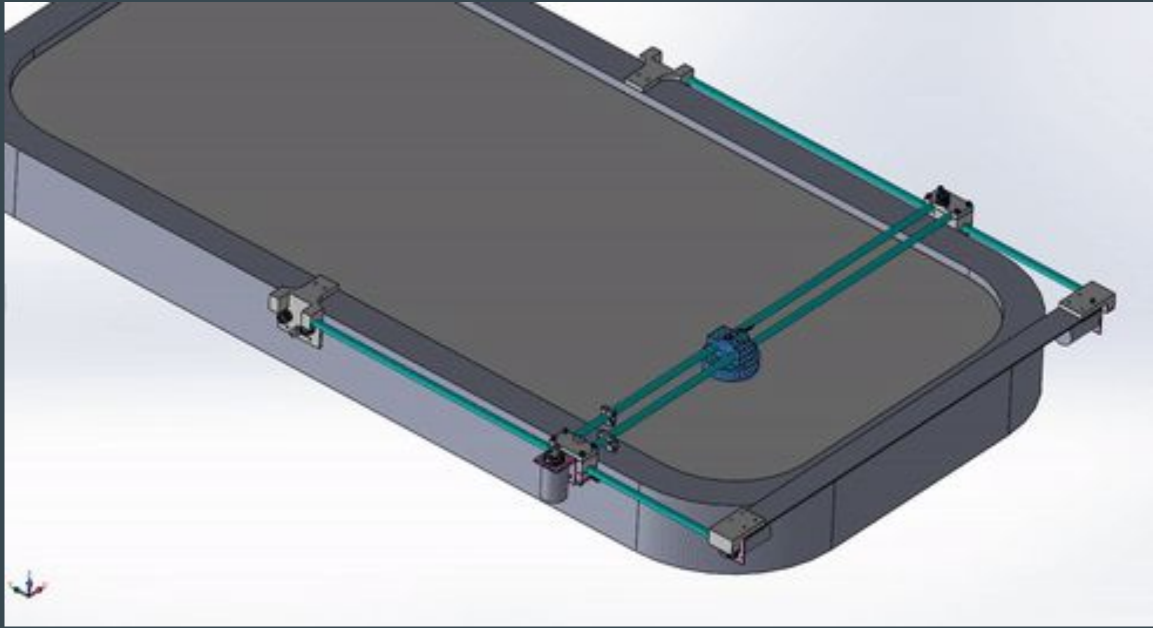
Mechanical Design

X-Axis Mechanism:

- 230W DC motor + encoder
- Linear rail + timing belt drive

Y-Axis Mechanism:

- 2 x 230W DC motors + encoders
- Linear rail + timing belt drive
- Connecting rod to mechanically link left/right movement



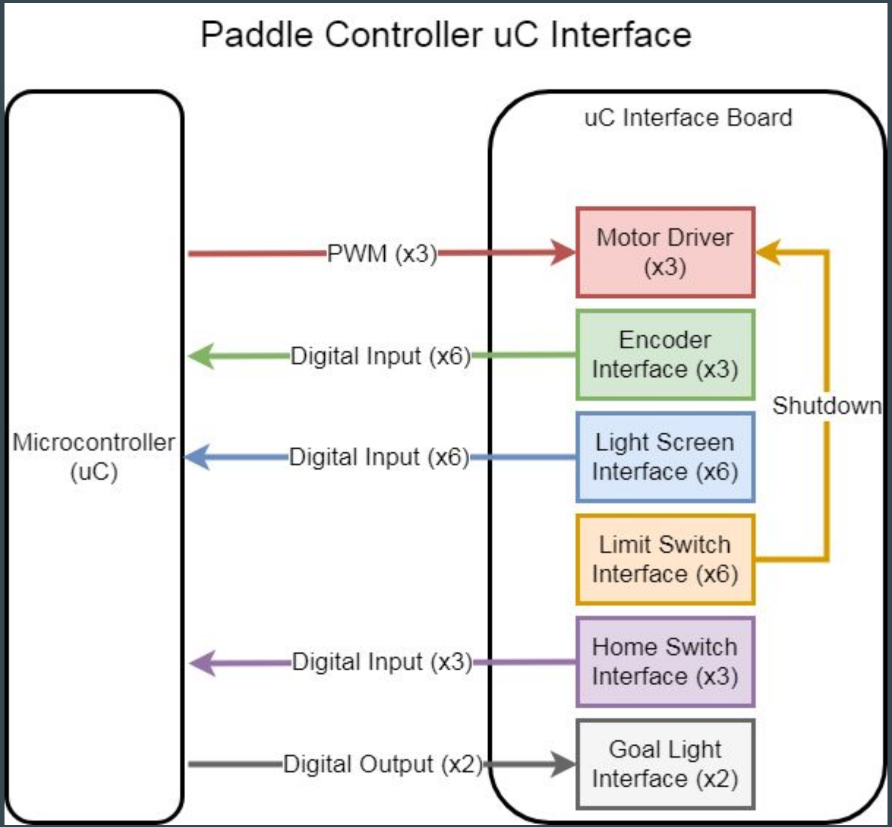
Electrical Design

Off-the-shelf MicroController (HCS12)

- Communicates with Master Controller via CAN
- Closed-loop motor control with quadrature encoder feedback

Custom Circuit Board

- High-power motor drivers
- Sensor interfaces
- Hardware-based motor safety shutoff



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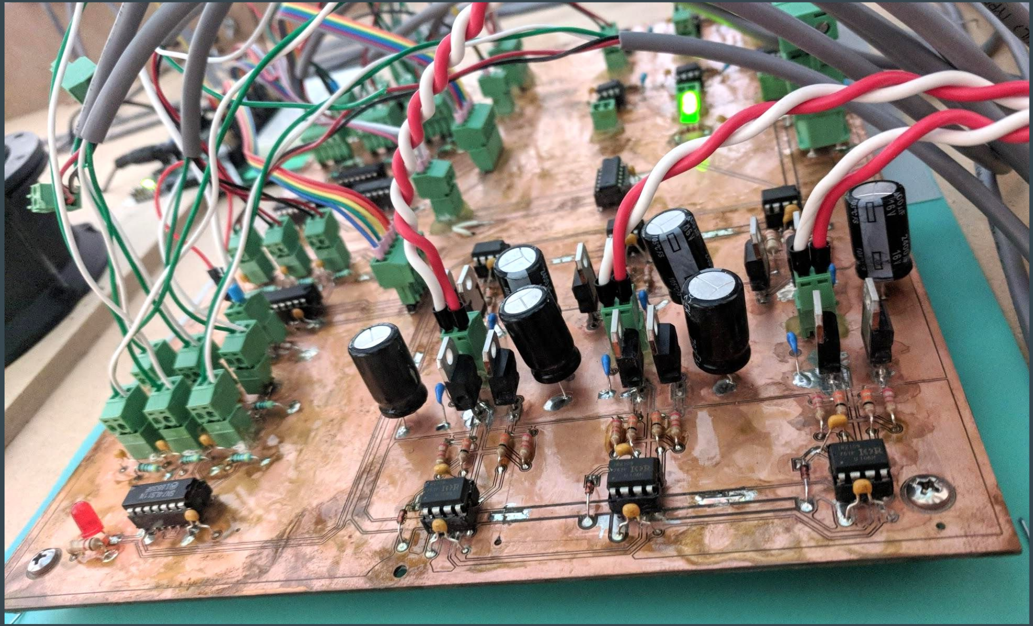


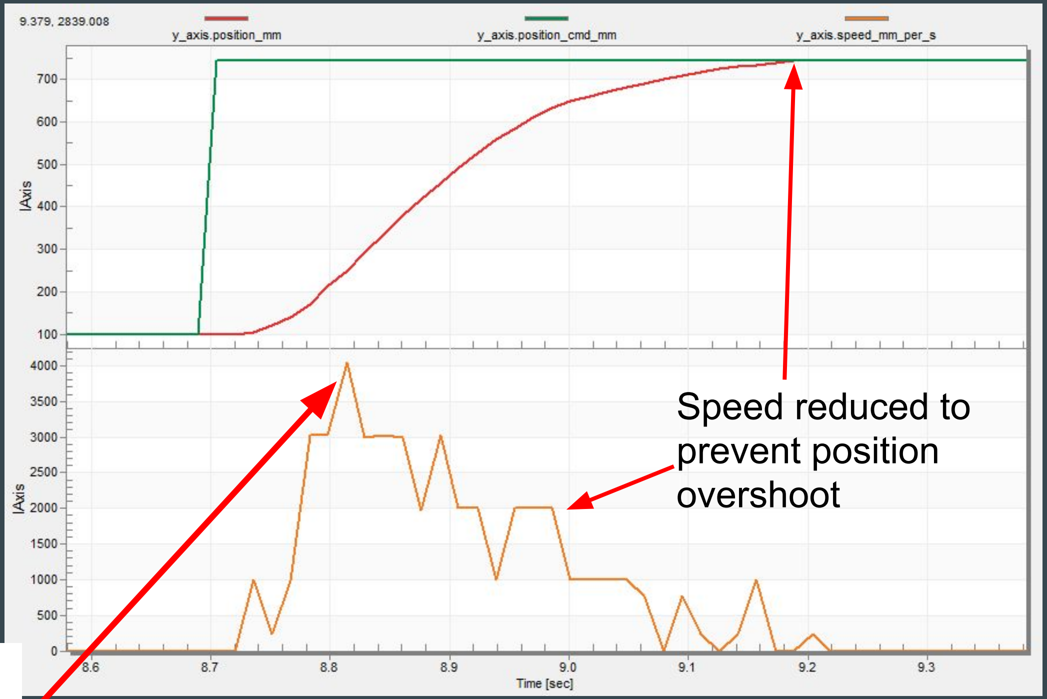
Safety Systems Design

1. Software monitoring of motor torque
   - Motors disabled if excessive resistance is detected
2. Light-screens surrounding robot
   - Motors disabled if human enters robots playing area
3. Limit switches placed at end of robot travel
   - Motors disabled in hardware if any limit switch pressed
4. Emergency-Stop mounted on human side of table
   - Removes power to robot when pressed

Implementation & Results

Prototype constructed that meets all high-level requirements.

- X-Axis speeds >5m/s
- Y-Axis speeds up to 4m/s
- Paddle position controlled to +/- 0.8 mm
- Multiple safety features to protect humans from high-speed robot



20% slower than theoretical max speed

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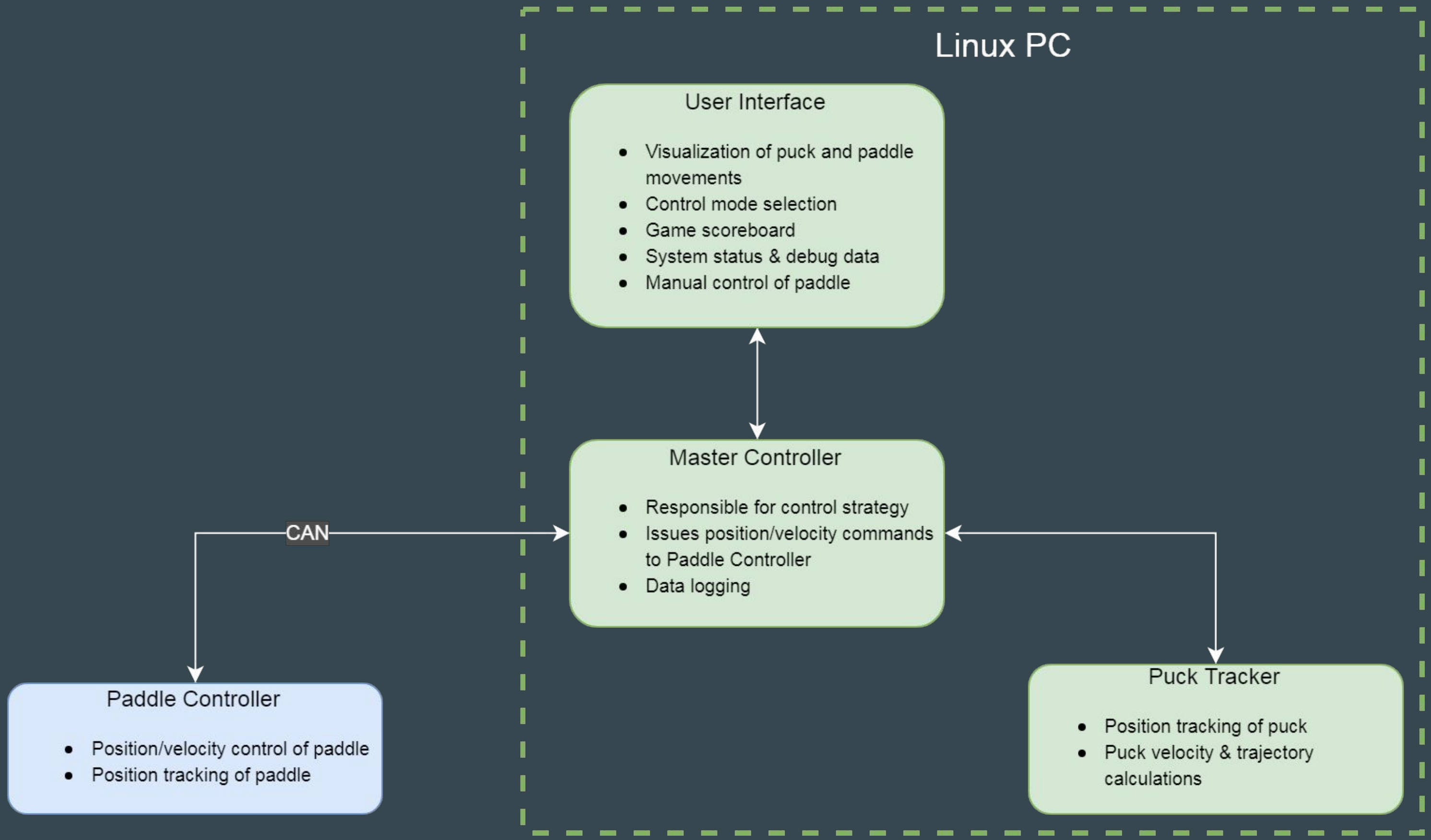
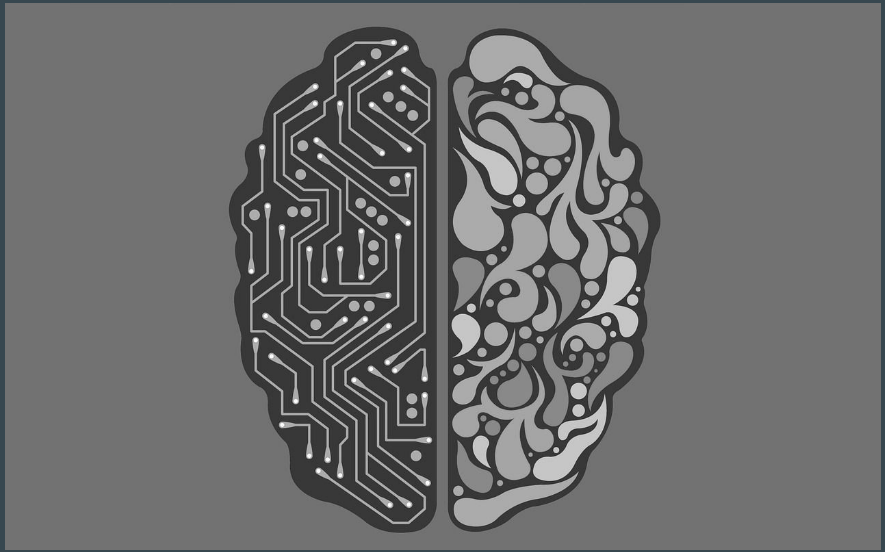
Project Status - Master Controller



Master Controller Implementation

- Central “brain” of the system
  - Makes control decisions based on data from all other modules
  - Issues movement commands to the robot
- Multiple control strategies implemented
  - User can select what strategy to play against



Defense Control Strategy

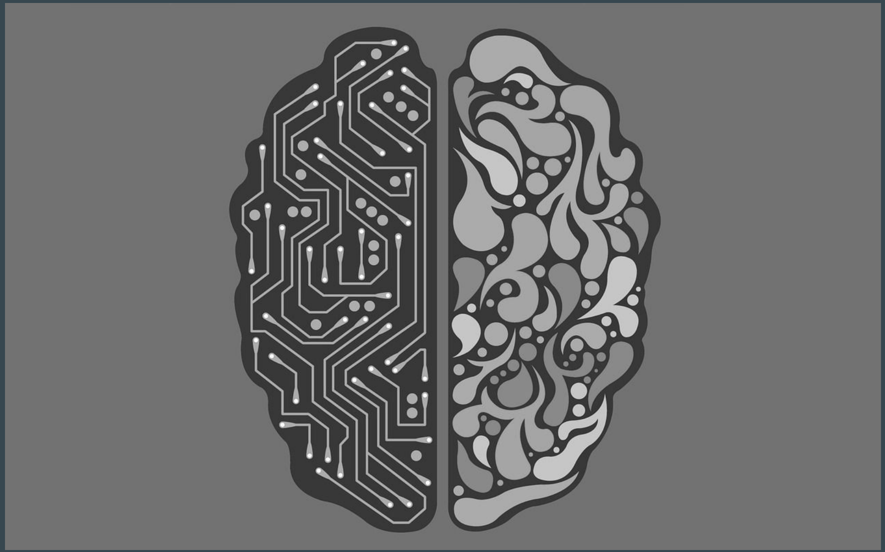
- Objective: Do not let the human score goals.
- Puck trajectory calculated from position measurements
  - Final position of puck predicted including bounces
- Robot blocks puck at Y=0
  - Returns puck to human if necessary

Offense Control Strategy

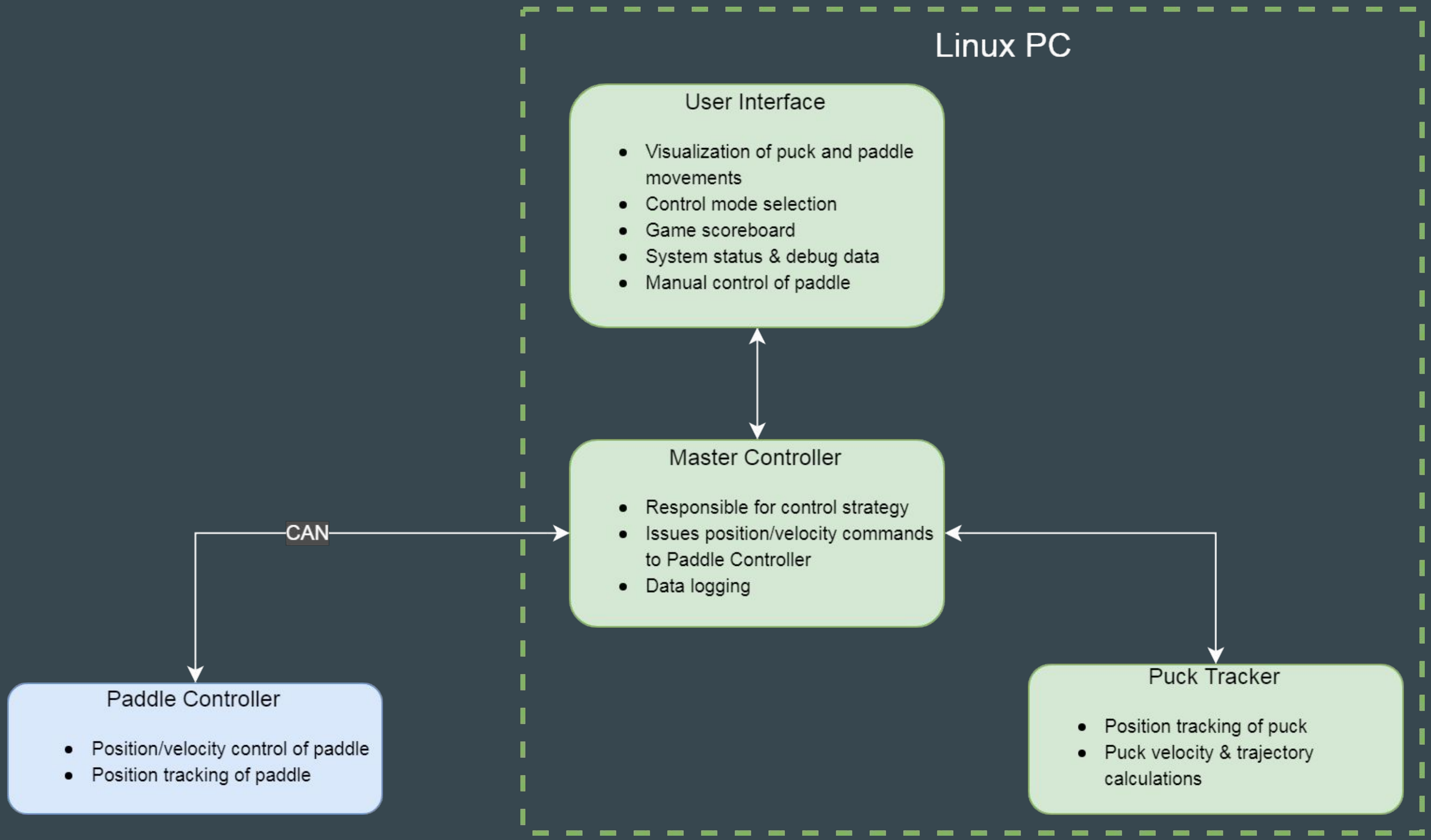
- Objectives:
  - Score goals on the human.
  - Do not let the human score goals.
- Robot attempts to hit the puck near the middle of the table
  - Attempts to hit puck with max speed
- Reverts to defensive movements if attack is not possible

Master Controller Results

- Robot can compete against human players
- Robot is highly competent at defense
  - Nearly impossible for humans to score when robot plays pure defense
- Robot is capable of scoring goals
  - More vulnerable on defense due to large distances travelled to attack puck

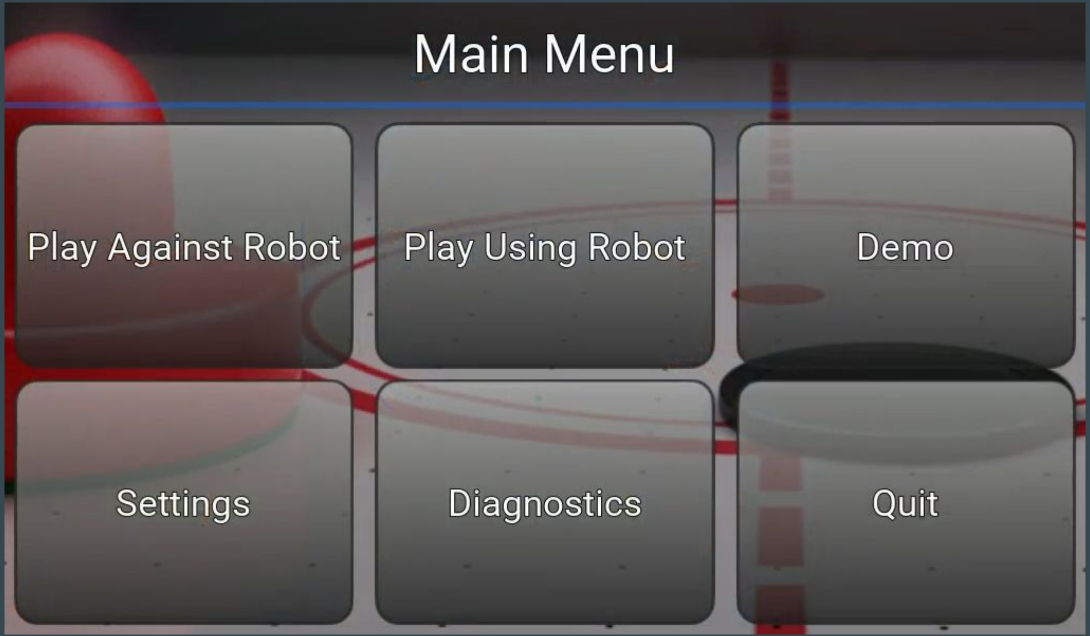


Project Status - User Interface



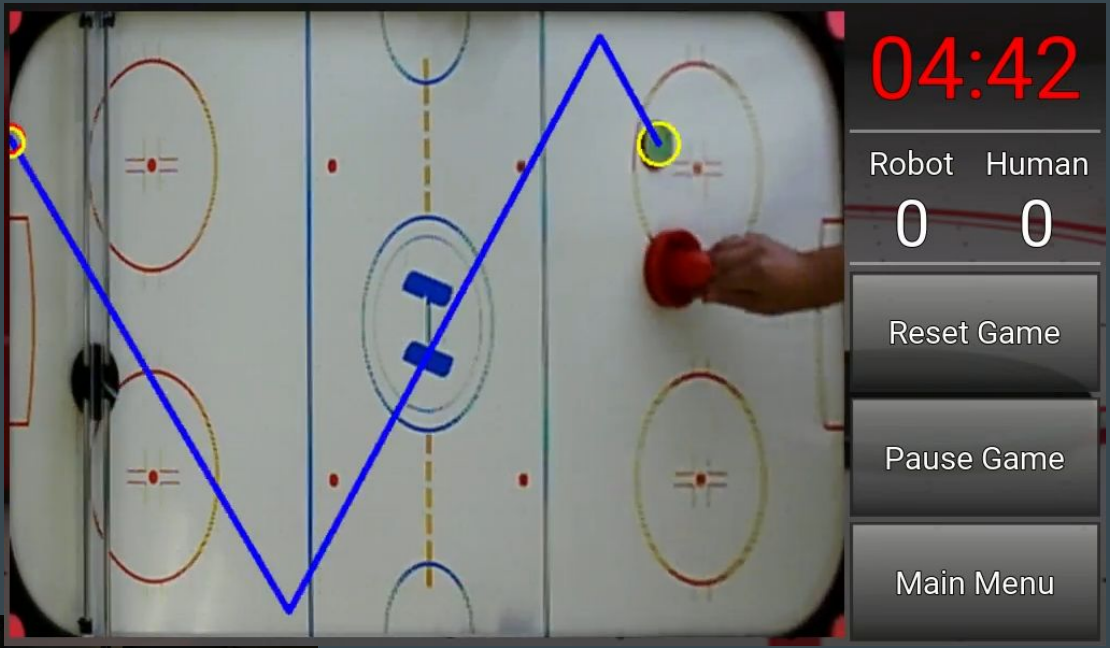
User Interface

- Kivy - Open source Python library
- Implemented on 10.1” capacitive touchscreen
- Provides user ability to:
  - Control settings
  - View system diagnostics
  - Manually control robot
  - Play against autonomous robot



Visualizing the Robot

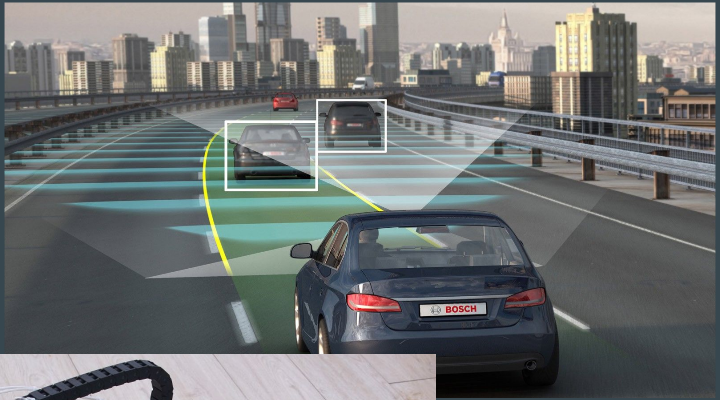
- Provides a real time view of the robots control strategy
- Game control
  - Start, Pause, and Reset game play
  - Game clock
  - Game score

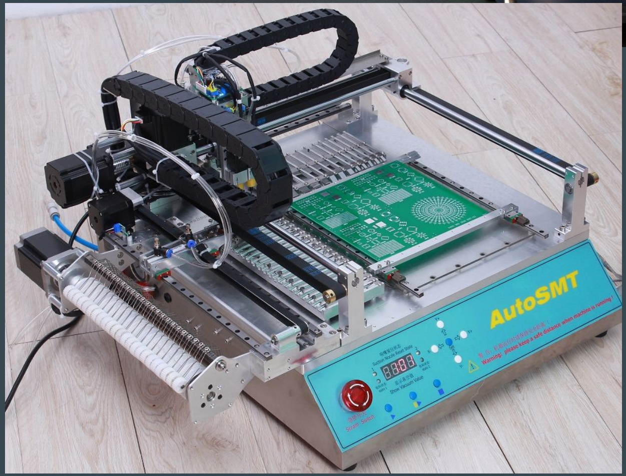


Future Development

Future Development - Other Applications

- Autonomous vehicles
  - Vision-based object detection and path prediction
- Military defense
  - Tracking and intercepting objects in motion
- Advanced manufacturing
  - High-speed position control
    - Pick and place machines
    - CNC machining
    - 3D printing





Future Development - Air Hockey Robot

- Prototype not designed for mass production
  - Redesign needed reduce costs and further improve safety
- Could be a popular game for arcades and bars

Future Development - AI

Control strategy development:

- Traditional control strategy implemented for Capstone
    - State based approach - attack, defend, return puck
- AI-based control strategy could allow for more “human-like” behavior
    - Neural Network being trained to play air hockey in Advanced Technical Elective course
    - Early results promising

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Demonstration

Project Demonstration Video

Thank You!