FOOSFIGHTER

MACRON DYNAMICS, INC.

ODrive High performance motor control

INKSMITH

DigitalOcean

Special thanks to:
James Tung
Eugene Li

1. PROBLEM DEFINITION

Aspiring foosball professionals require ***another player*** to train against and develop their skills

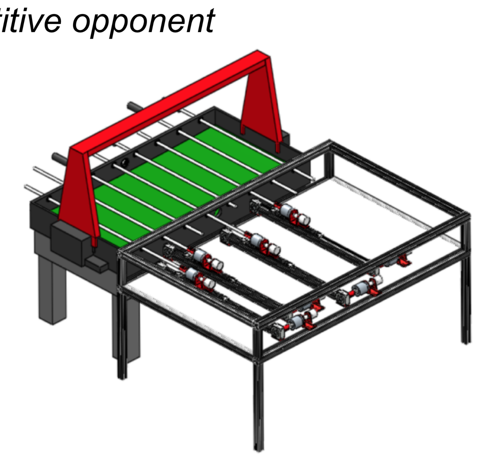
150,000
Annual Foosball Table Sales

520 Million
Market Size in USD

70,000
Active Tournament Players

2. MISSION STATEMENT

*FoosFighter is an **automated foosball** opponent capable of training human players by substituting as a competitive opponent*

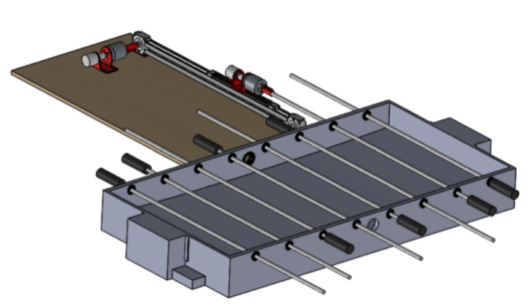


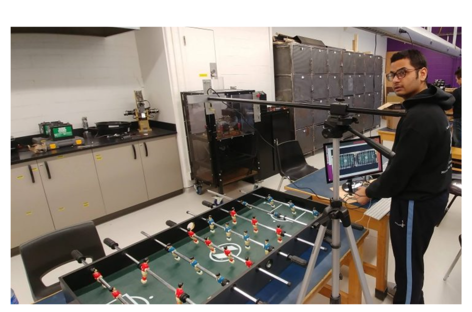
3. CONSTRAINTS

- Play a complete game of foosball autonomously
- Achieve rotational speeds greater than 150[RPM]
- Move the rod linearly at speeds greater than 1.8[m/s]
- Translate the rods along its entire stroke length
- Detect ball position in real-time

4. DESIGN PROTOTYPE

A single prototype was created using a linear actuator and two motors to control the movement of a single rod. Elementary ball detection was built using a low FPS camera to demonstrate ball-tracking functionality.





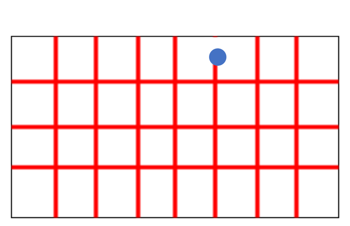
5. DESIGN ALTERNATIVES

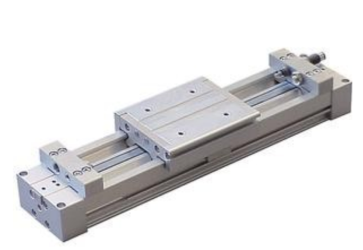
LASER GRID FOR BALL DETECTION:

+ Not susceptible to varying light levels
- Low resolution
- Design affects table structure
- Large number of components

PNEUMATIC ACTUATORS FOR MOVEMENT:

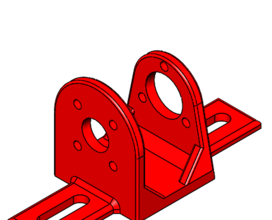
+ High power
+ High speed
- Low accuracy
- Requires compressed air

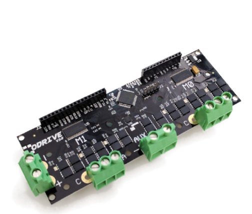




6. MOVEMENT

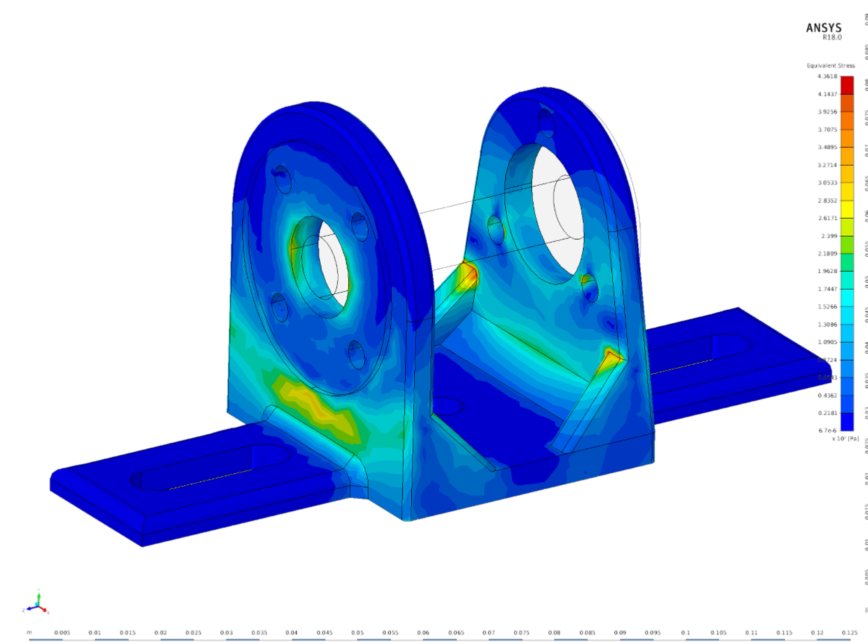
- Eight 1.6kW motors controlled by four *ODrive* controllers generate rotary rod movements
- Four *Macron* MSA-PSC belt drive actuators convert motor action into linear rod movements
- *ODrive* motors are connected to base and linear actuators using custom 3D printed parts





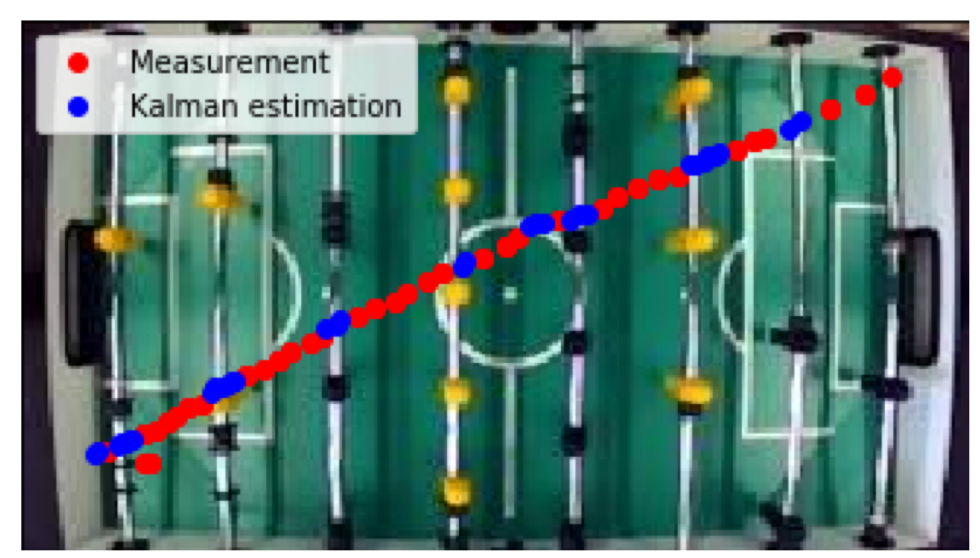
7. FINITE ELEMENT ANALYSIS

- The first point of failure is the motor mounts between the linear actuators and the motors
- This is acceptable because damage to the system is not likely to occur as a result. The motors will stay attached to the rod following yielding in the motor mount
- From FEA it is expected that the motor mounts will yield at a force of 1365[N]
- Maximum expected force during regular movements is 30[N]. Crashing into foreign objects can cause significant increases in the encountered force but still within the yielding range



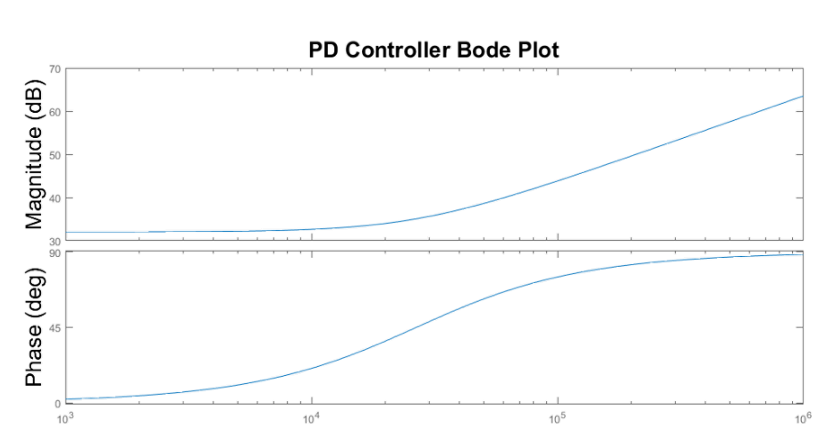
8. COMPUTER VISION

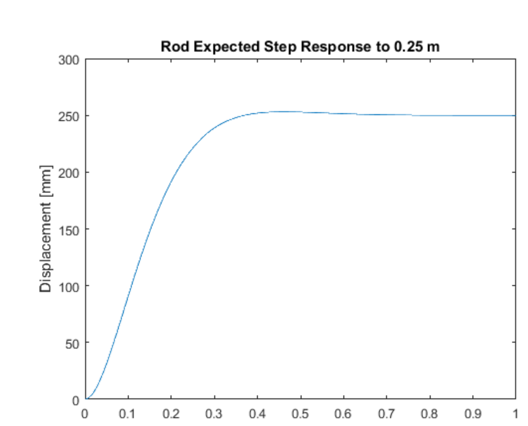
- Stereo Camera operating at 100 FPS and 135x250 frame size to capture ball movement
- Ball detection is performed by combining color detection, sliding windows and frame differential
- *Kalman Filter* is used to reliably estimate the position of the ball despite heavy occlusion



9. CONTROL

- Ball trajectory is predicted using estimated states provided by the *Kalman Filter*
- Rods are driven to the predicted position by the *ODrives*
- Rods are modelled as a mass damper system of mass 2.62[kg] and damping coefficient 57.4[Ns/m]
- Damping value is determined by analyzing the rod movement in slow-motion
- Rods are controlled using a PD controller with feedback from optical encoders
- Previous ball position and velocity are used to predict current ball position
- *Kalman Filter* provides good performance in combating the frequent interruptions from occlusion





- Kalman Filter Algorithm
  - At each time step, t, update both sets of beliefs
    1. Prediction update

$$\bar{\mu}_t = A_t \mu_{t-1} + B_t u_t$$
$$\bar{\Sigma}_t = A_t \Sigma_{t-1} A_t^T + R_t$$

    2. Measurement update

$$K_t = \bar{\Sigma}_t C_t^T (C_t \bar{\Sigma}_t C_t^T + Q_t)^{-1}$$
$$\mu_t = \bar{\mu}_t + K_t (y_t - C_t \bar{\mu}_t)$$
$$\Sigma_t = (I - K_t C_t) \bar{\Sigma}_t$$

  - Kalman Gain, K_t
    - Blending factor between prediction and measurement

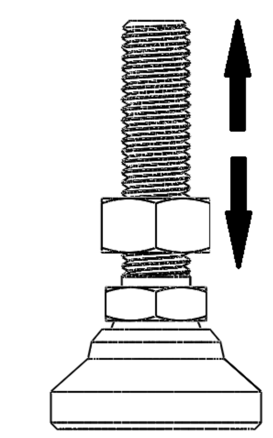
(Waslander 2017)

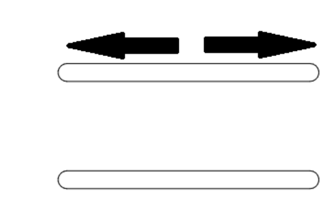
10. GAME STRATEGY

- Estimated ball state and trajectory calculations are combined to determine rod placement
- Predicted ball path is used to move the closest foosman into the trajectory of the ball
- Ball heading determines whether the foosmen block or avoid the ball for defence and offence
- Kicking action is timed based on the path and velocity of the ball
- Goalie plays conservatively by first blocking the ball before kicking
- The remaining foosmen play offensively by immediately kicking the ball

11. DESIGN ADVANTAGES

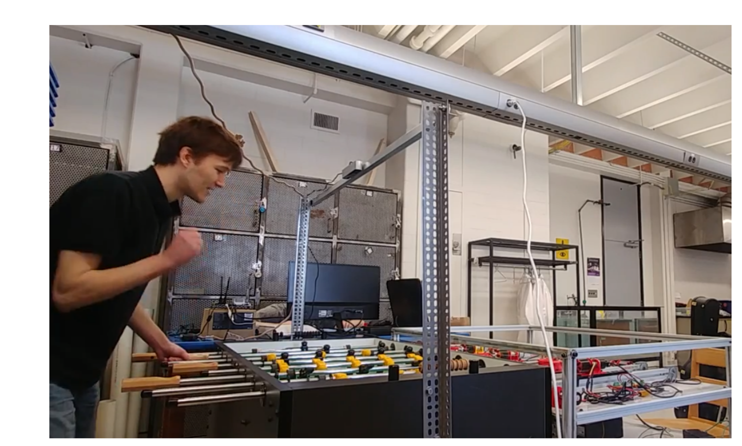
- Overtrains players using a combination of intelligent decision making and mechanical superiority
- Requires no alteration to the existing foosball table
- Slots in the acrylic base allow *FoosFighter* to accommodate tables with different rod spacing
- Levelling feet allows accommodation of foosball tables of varying height
- Design of the shaft couplers permits attachment to warped rods





12. RESULTS

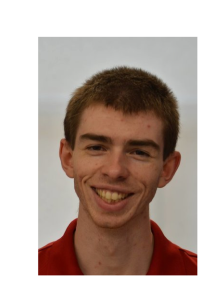
- Max linear rod speed of 9[m/s]
- Rotational kicking speed up to 300[rpm]
- Capable of moving the rods along their entire stroke length
- Detects the ball in real-time with an acceptable delay of 2.5[ms]
- Utilizes elementary AI techniques to predict ball movement and placement of foosmen
- Capable of performing all the actions of a foosball player

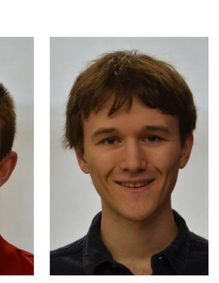


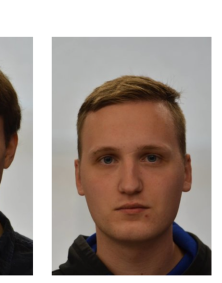
13. RECOMMENDATIONS

- Improve the gameplay experience using Reinforcement Learning
- Additional difficulty settings to train users of all levels
- Tutorial modes and lessons to fine tune skills
- Automatic motor and camera calibration to simplify setup
- Dampers to reduce table vibrations
- Additional cameras to reduce occlusion
- Include user interface to operate *FoosFighter*

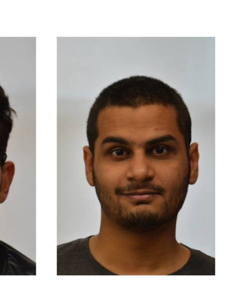
14. TEAM


Alex


Kevin


Matt


Mohamed


Sarim

FoosFighter.com