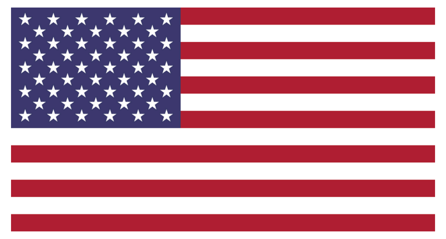
Elite-Nexus

USA Open Soccer



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Links

Abstract

Team Elite-Nexus consists of students from the Princeton Soccer Robotics Club and Trinity School Robotics. New features such as an aluminum mirror, custom solenoid, and HSV color tracking were difficult additions bringing forth improved ball control. Throughout the season we conducted various experiments and design iterations for localization and enemy avoidance to produce the most efficient goal-scoring algorithm. Our robots are heavily reliant on 3D-printed parts for a lighter yet rigid structure bringing the total cost to around USD 1500. Our robots are the product of 1200+ hours and uncountable failures that ultimately lead to the final product.

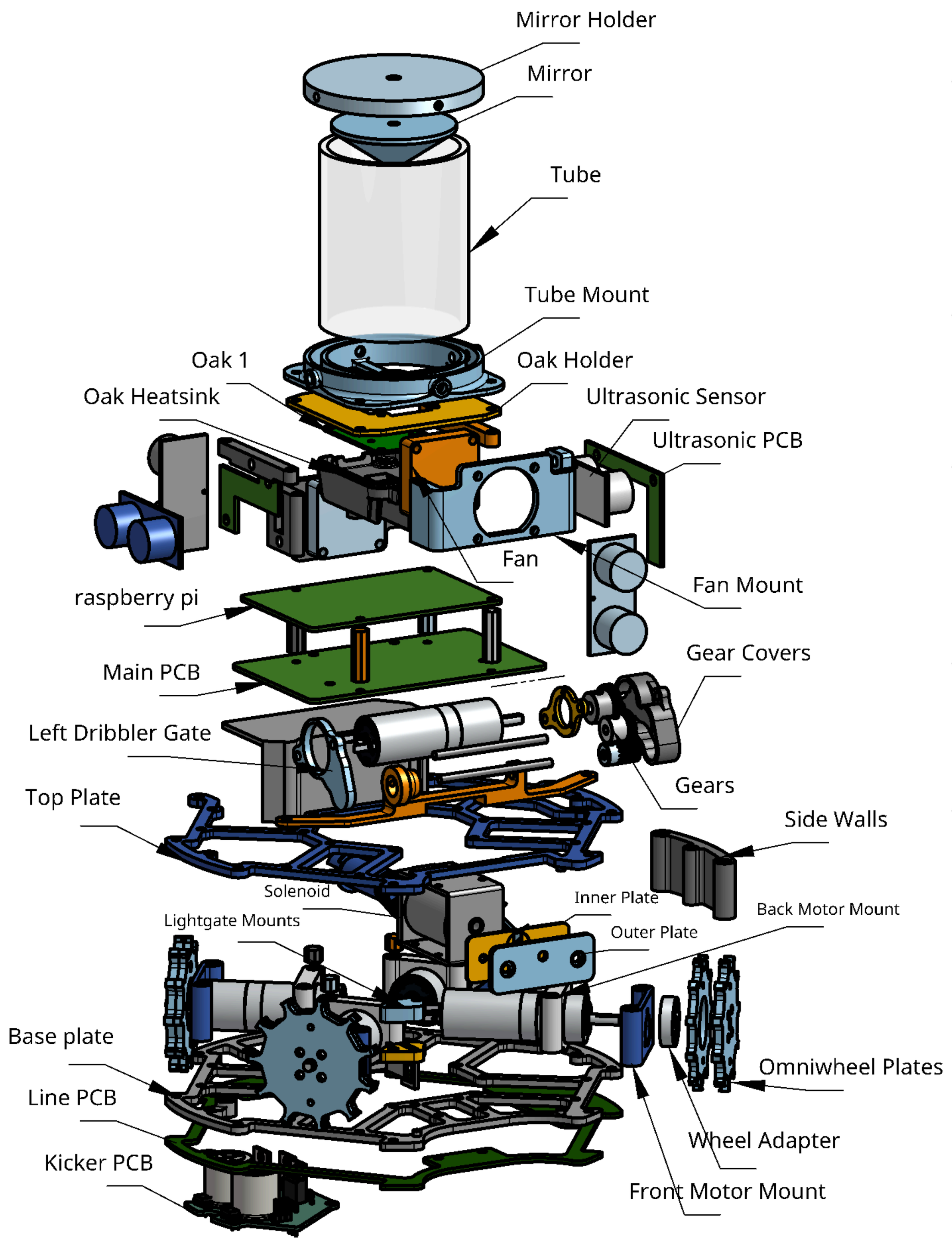


Fig 1. Robot Exploded view

Electrical Design

Line PCB

- 24 LEDs and photodiodes arranged to fit the shape of the robot
- Custom Python scripts were created to automate the repetitive placement process
- Allows for quicker and more efficient detection and avoidance of line, reducing chances of the robot going out of bounds
- 3 ADCs used as a multiplexor to reduce the number of pins used on the teensy
- 10-pin header for connection to the main PCB utilizing an IDC connector

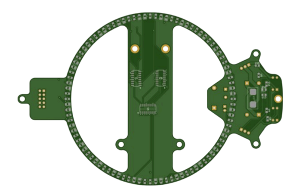


Fig 2. 3-D Rendered Image of Line PCB

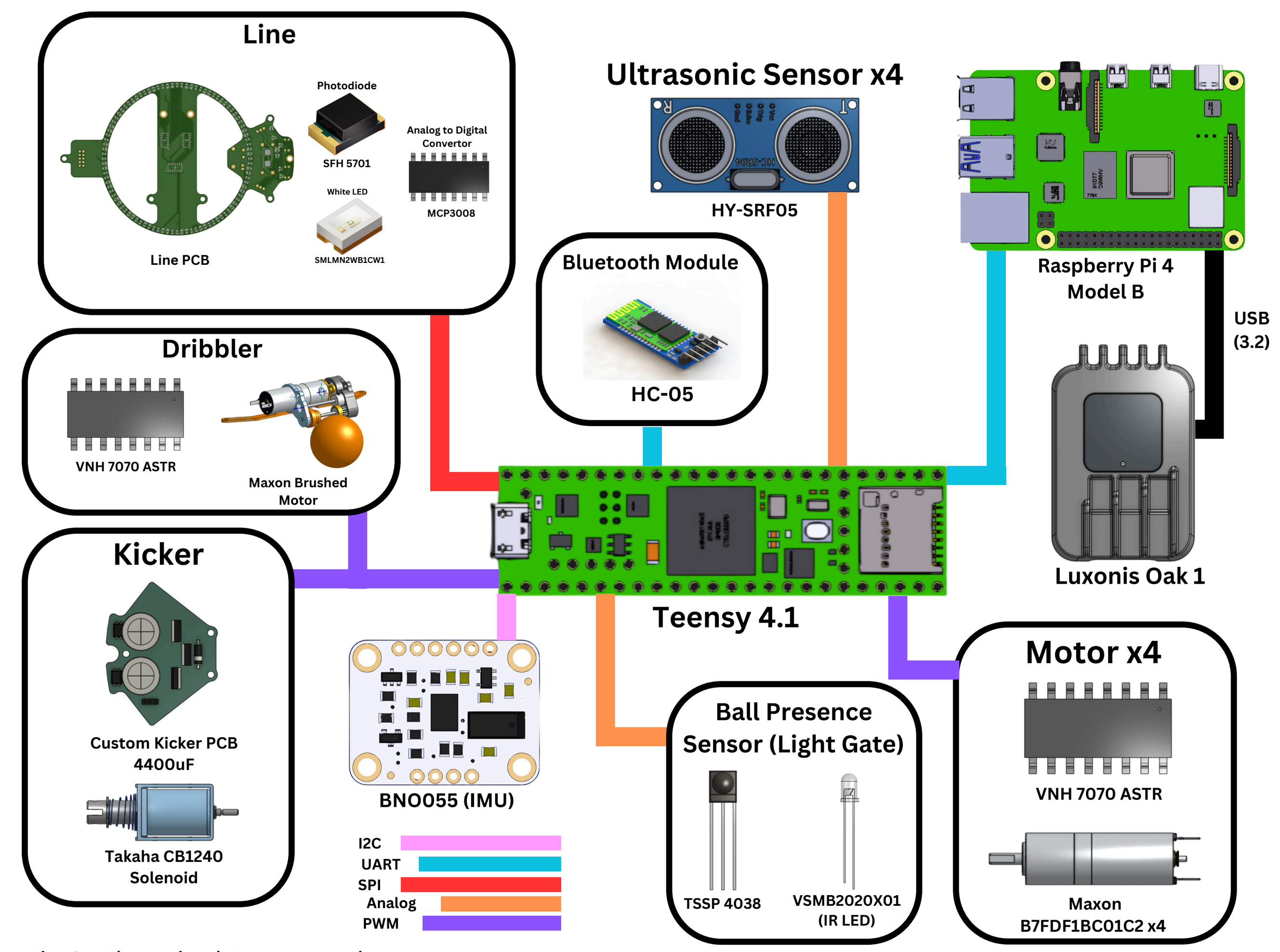


Fig 3. Electrical Topography

Custom Kicker Design

- Custom wound solenoid with 22AWG wire to increase kicker strength
- 48V made using XL6009 based boost converter
- High current from charge stored in two 2200uF capacitors
- High Voltage control using MOSFETs
- Optocouplers used to control MOSFETs using isolated low-voltage signals
- Secondary P-Channel MOSFET isolates the circuit to protect against rapid discharge of the battery

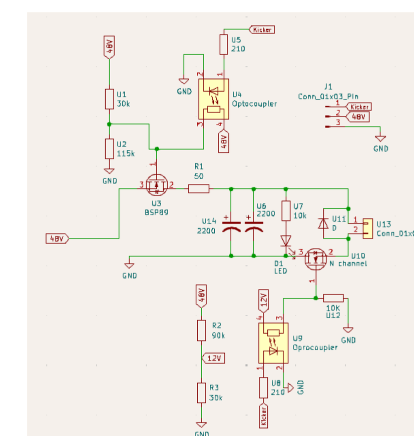


Fig 9. Kicker Circuit Schematic

Results

Hyperbolic Mirror Manufacturing

- Experimented with thermoformed mirror foil but it had a very deformed image
- New Mirror made using CNC Lathe with aluminum 6061 for lightweight mold
- Aluminum is then wet sanded progressively up to 3000 grit
- Aluminum polish is applied in 2 separate coats for the ideal mirror finish
- This produced a very clear image and allowed us to have a great starting point for AI and color detection
- Used a highly constrained sketch in CAD to calculate the perfect mirror shape factoring in height and size of the field and goals

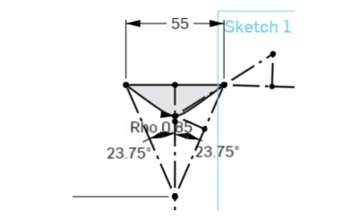


Fig 4. Sketch of Mirror Mold

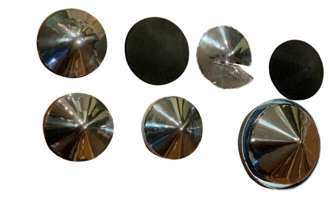


Fig 5. Mirror Iterations

Fig 6. Sanding and Polishing mirror

Fig 7. Before and after polishing the mirror

Custom Kicker Winding

- This year we had decided to manually wind our kicker which actually greatly increased our output power.
- We use the magnetic field equation: B=u(N/L)i to calculate our desired output.
- Discovered that in order to increase kicker strength, we simply had to make the current in the solenoid greater while keeping turn density the same.
- Rewinded the solenoid with thicker wire which would reduce the resistance, however would also reduce turn density
- This led us to 22 Gauge wire as a happy medium for the strongest kicker possible

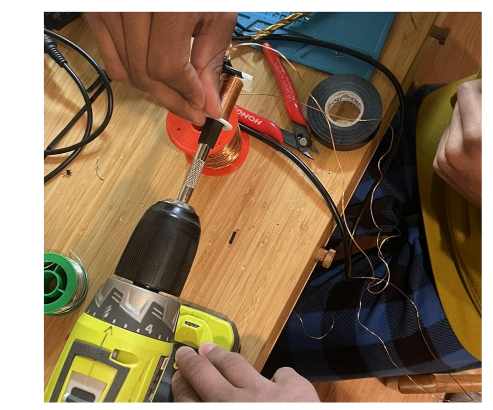


Fig 8. Winding Kicker

Multi-Threading in Color Tracking

- Initially, we wrote HSV color tracking in Python but soon realized that the low FPS was not usable
- Therefore we rewrote the OpenCV program fully in C++ which resulted in around 15 FPS. We then performed CPU profiling to further identify optimizations that we could perform. To boost FPS, we utilized multiple threads for each element of the field boosting FPS up to 4x.

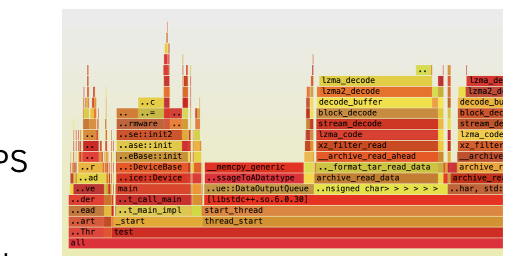
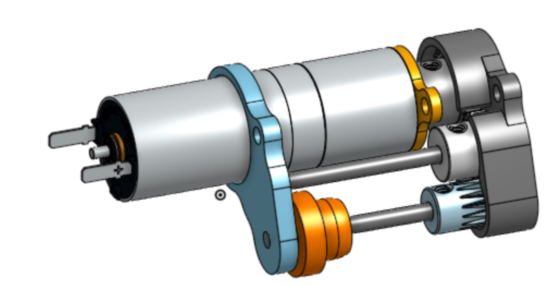


Fig 10. CPU Flame Graph

Mechanical Design

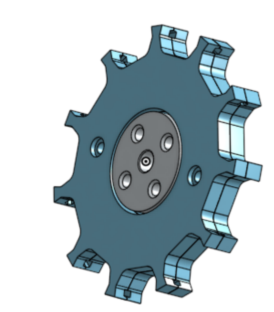
Dribbler



- Lightweight, fully 3D printed dribbler
- High speed brushless motor with custom pulleys
- Dual Dribbler for precision control
- Placed on a pivot absorb shock from impacts
- Rubber Tubing used for gripping ball securely at high RPM

Omniwheels

- 360 movement
- The **X-drive** design increases speed and torque at all angles
- Integrated Motor shaft mounting to reduce space
- Four plates and two Layers of rollers increase traction
- 3D printed design reduces cost



Software Design

Object Detection

- We use **Clairvoyance** to segment the image at anchor points (marked as red dots) corresponding to pure HSV forms (Yellow, Blue, Orange).
- Each anchor point is used to generate a precise object mask. We then extract the matrix of pixel HSV values from this mask and run stochastic gradient descent to optimize both IoU and cosine similarity between the HSV-thresholded binary mask and the MobileSAM mask.
- A **Desmos** exponential regression was used to relate pixel and cm distance

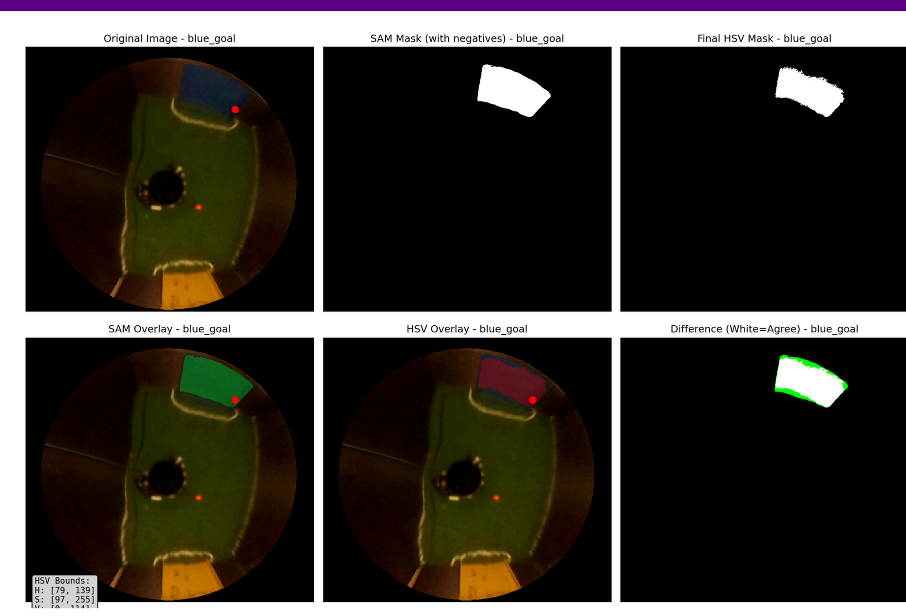


Fig 11. Clairvoyance Object Detection

Hidden Ball Detection

- When our defense robot is unable to detect the ball the offense robot can calculate the absolute ball position and send it over to the other robot
- The defense robot uses this data to get relative angle to detect and block "ball hiding" strategies

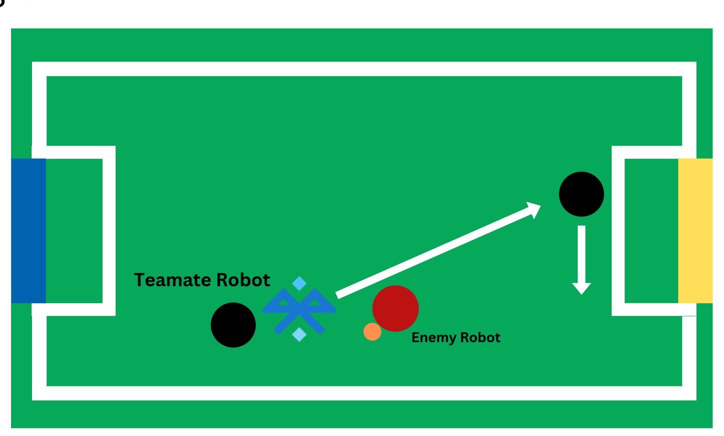


Fig 15. Strategy diagram of robots using Bluetooth communication to locate and transmit hidden ball location

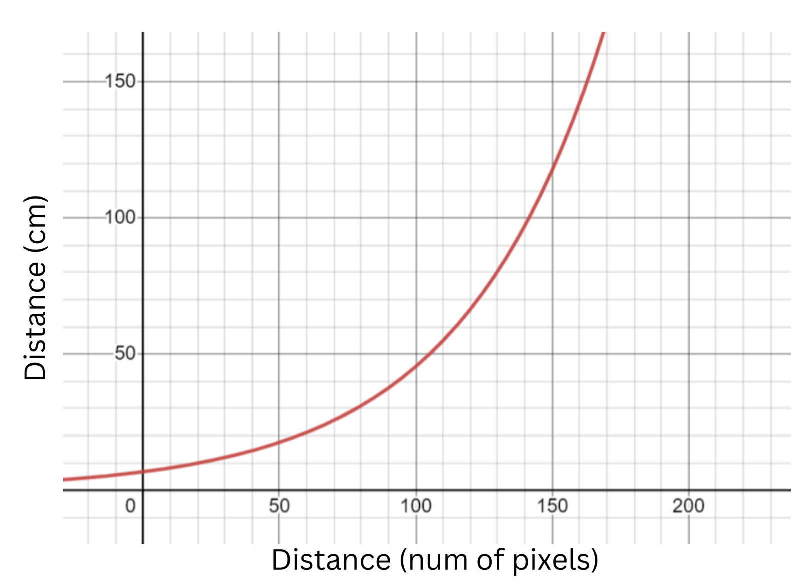


Fig 12. Relation between pixel distance and actual distance obtained from exponential regression

Trajectory Planning: Ball Tracking & Path Optimization

- We first compute the ball's velocity relative to the robot over a fixed time interval—adding a derivative term for responsive control—and localize its position by vector-adding sensor-derived displacement vectors. An exponential function smooths the raw interception angle, producing the optimal path to the ball. We then triangulate goal angles detected by the camera to orient the robot and trigger the kicker, minimizing total scoring time.
- **Sniper** uses a cubic Bézier curve for tricky-angle shots. Control points are chosen so the curve's endpoint lands exactly on the ball, and its slope (d/dx) is set to $\frac{y_{goal} - y_{ball}}{x_{goal} - x_{ball}}$ by solving the corresponding ODE.
- **Midas** decides defensive action by solving for the positive real root of

$$\frac{v_i \pm \sqrt{v_i^2 + 2\,a\,\Delta x}}{a}$$

where v_i is initial velocity, a is acceleration, and Δx is distance to the ball. If an opponent would reach the ball first, the goalie enters block mode (matching the ball's x-position); otherwise it switches to intercept mode.

Process

Prototyping

- The design process for the majority of our robots included numerous trial and error instances for new design
- **Start with sketches → the best ideas are designed in OnShape→ 3D printed in PLA**
- New Parts and tools are added to our detailed bill of materials to keep inventory

onshape

PCB Designs

- Rigorously verify every PCB iteration (fab is expensive and slow)
- New sensors are first proposed due to significant constraints in robot ability
- **In-depth component research → Lay out in KiCad → manufacture → assemble by hand soldering**

KiCad

Team Communication

- Our team relies on Discord and in-depth to-do lists to stay up to date with all tasks that are completed each day. Each new idea and problem is solved using hours of group debugging sessions

Discord

Poster by Aniket Kokate and Apollo Touch, edited by Madhavendra Thakur