Robotics Traveling Van

Andy Babcock

David Jimenez

Kyle Draper

Kaden Zaremba

Capstone Professor: Professor Solis

Project Sponsor: Michael Schafer

Northern Arizona University - Steve Sanghi College of Engineering

The Project

The field of STEM contains some of the most difficult concepts to understand. Without a proper introduction to the field, STEM can be an intimidating subject for students to want to pursue. To continue growing community and interest in this field, we will expose young students to simple STEM concepts.

The Robots!

Two physics-based educational robots which show simple physics and robotics for kids.

The Goal

- Make multiple educational robots to be deployed in the Robotics Traveling Van
- Make these robots interesting and engaging
- Demo the Robots to students to get them interested in STEM
  - Teach fundamental concepts on math, physics, and robotics

Customer Requirements

1. Make it pretty
2. Make it functional
3. Make as many as possible

CUSTOMER REQUIREMENT	CR MET? (✔ OR X)	CLIENT ACCEPTABLE (✔ OR X)
CR1: Operating Space	✔	✔
CR2: Battery Powered	✔	✔
CR3: Active Dynamic Balancing	✔ Partial	✔ (R1 Descoped)
CR4: Kid-Friendly	✔	✔
CR5: Durability	✔ Partial	✔
CR6: Inexpensive	✔	✔
CR7: Interactive Interface	✔	✔

Parts List: Inverted Pendulum Robot

← GM3865-520 DC

470uF Electrolytic Capacitors
And 1A 20V Schottky Diode →

← DRV8871 Motor Driver

14.6 Volt 2A Battery Charger →

← AS5600 Magnetic Encoder

4S 30A 12.8V BMS →

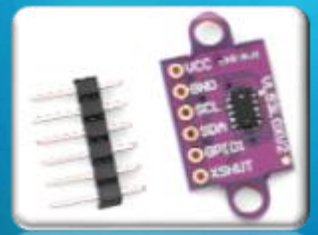
3.3V Buck Converter →

Raspberry Pi Pico /
RP2040 Board →

3.2V LiFePO4 Battery →

ST7796S 4.0" LCD
Touchscreen →

Parts List: Ball Beam Balance Robot



← VL53L0X Time of Flight Sensor

470uF Electrolytic Capacitors
And 1A 20V Schottky Diode →

← TMC2209 Stepper Motor Driver

14.6 Volt 2A Battery Charger →

← NEMA 17 12V Stepper Motor

4S 30A 12.8V BMS →

3.3V Buck Converter →

Raspberry Pi Pico /
RP2040 Board →

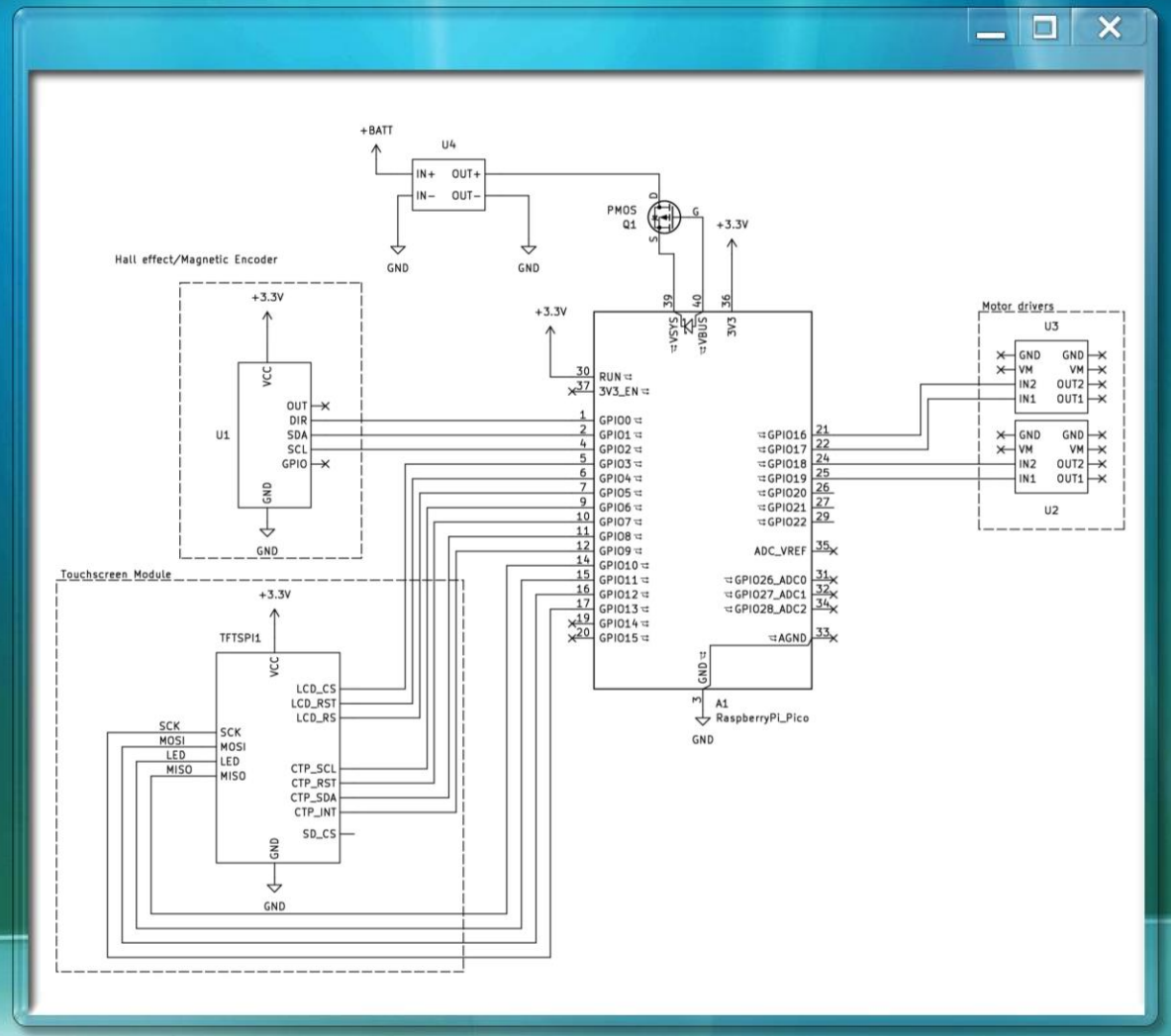
3.2V LiFePO4 Battery →

ST7796S 4.0" LCD
Touchscreen →

Budget

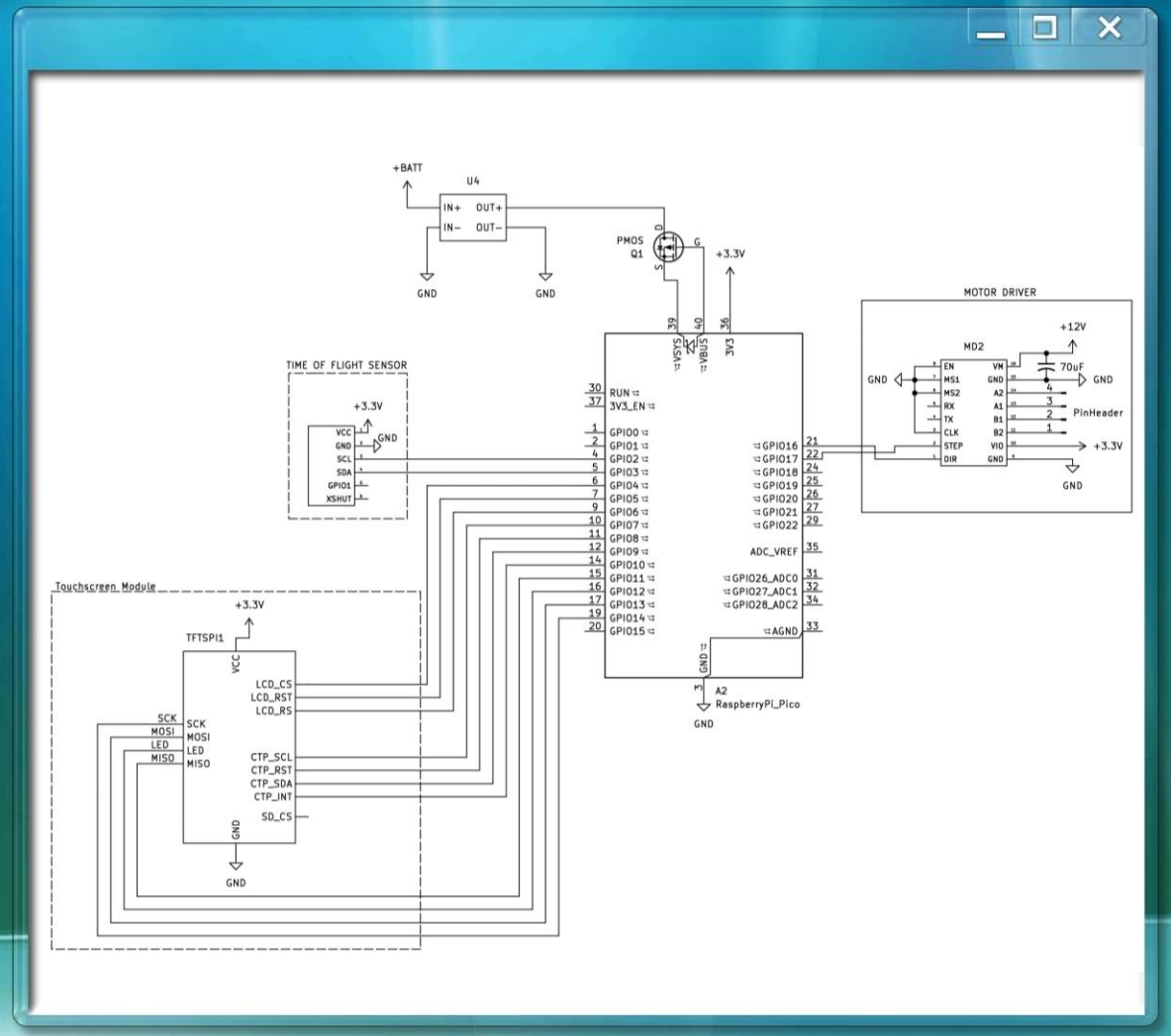
- Total budget: $5000 + $500 from fundraising at Panda Express
- Total spent: $2500
- Raw cost for IPR: $94
- Raw cost for BBB: $82

Circuit Design & Code: IPR




```
cartPID.Compute();
float force = output;

if (fabs(angle - set_point) < 2.0f) {
  force = 0.0f; // deadband for perfect balance
}

// force ⟶ accel ⟶ speed ⟶ PWM
float acceleration = force / CART_MASS;
current_speed += (acceleration * dt);

// slight damping to prevent infinite drift
current_speed *= 0.98f;

float target_pwm = current_speed * SPEED_TO_PWM_RATIO;
set_motors(target_pwm);
```

Circuit Design & Code: BBBR




```
uint16_t mm = sensor->readRangeContinuousMillimeters();
if (!sensor->timeoutOccurred() && mm < 1200) {
  distance_val = (float)mm / 10.0f; // mm to cm

  myPID->Compute();
  motor->set_angle(control_output);

  current_distance = distance_val;
  current_speed = control_output;
```

Many, Many Issues

- Touchscreen issues from overdrawing Pico
  - Very few libraries for the RP2040 AND our specific screen
- Consistently fried Picos
  - Half our oversights, half issues out of our control

Robot 1:

- Potentiometer initially used was not accurate enough
- Lost power under heavy loads

Robot 2 :

- TMC2208 & TMC2209 have overheating issues
  - They fail catastrophically and send the motor voltage down the data lines
- Parts not working out of box

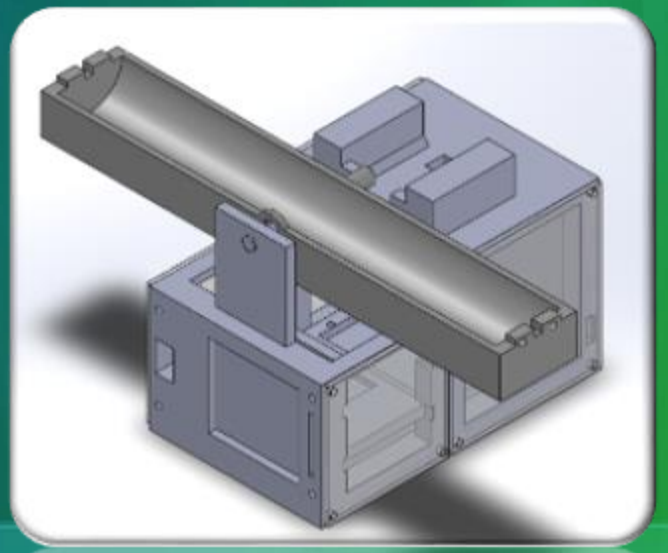
Development Time

Fall 2025

- Made the first rough draft versions of the CAD model, circuit, and software
  - Migrated away from Arduino and began overhaul of the CAD models
  - Prototyping

Spring 2026

- Complete overhaul of both CAD models
- Major debugging and troubleshooting
- (Almost) total code rewrite
- Change sensor and SoC choice
- Design + print circuit board
- Implement interactive touchscreen



Engineering Requirement Tests

ENGINEERING REQUIREMENT	TARGET	TOLERANCE	MEASURED/CALCULATED VALUE	ER MET? (✔ OR X)	CLIENT ACCEPTABLE (✔ OR X)
ER1: Overall Dimensions	< 12 x 12 x 12 in	+ 1 inches	Verified < 11.8 in^3	✔	✔
ER2: Power Run Time	> 30 minutes	- 5 mins	Extrapolated > 135 mins	✔	✔
ER3: Control Hardware	Raspberry Pi Integrated	N/A	Verified Integrated & Functional	✔	✔
ER4: Electrical Safety	Safe internal wiring	N/A	Verified via inspection	✔	✔
ER5: Drop Test	Survive 36 inches	- 2 inches	Survived 40 in. (Shell Only)	✔ (Partial)	✔
ER6: Manufacturing Cost	< $500	+/- $50	About $240 per unit	✔	✔
ER7: PID Settling Time	< 15.0 seconds	+/- 2.0 sec	~9.0 seconds (Average)	✔	✔
ER8: Sharp Edge Radii	No sharp corners	N/A	Visually inspected PLA	✔	✔
ER9: Pinch Clearance	< 0.210 in	+ 0 inches	Verified with CPSC gauges	✔	✔
ER10: Emergency Stop	Instant power cut	< 1.0 sec	Verified functional (Robot 2)	✔	✔
ER11: Visual Feedback	GUI displays data	N/A	GUI functional (Robot 2)	✔ (Partial)	✔

Sensor Values

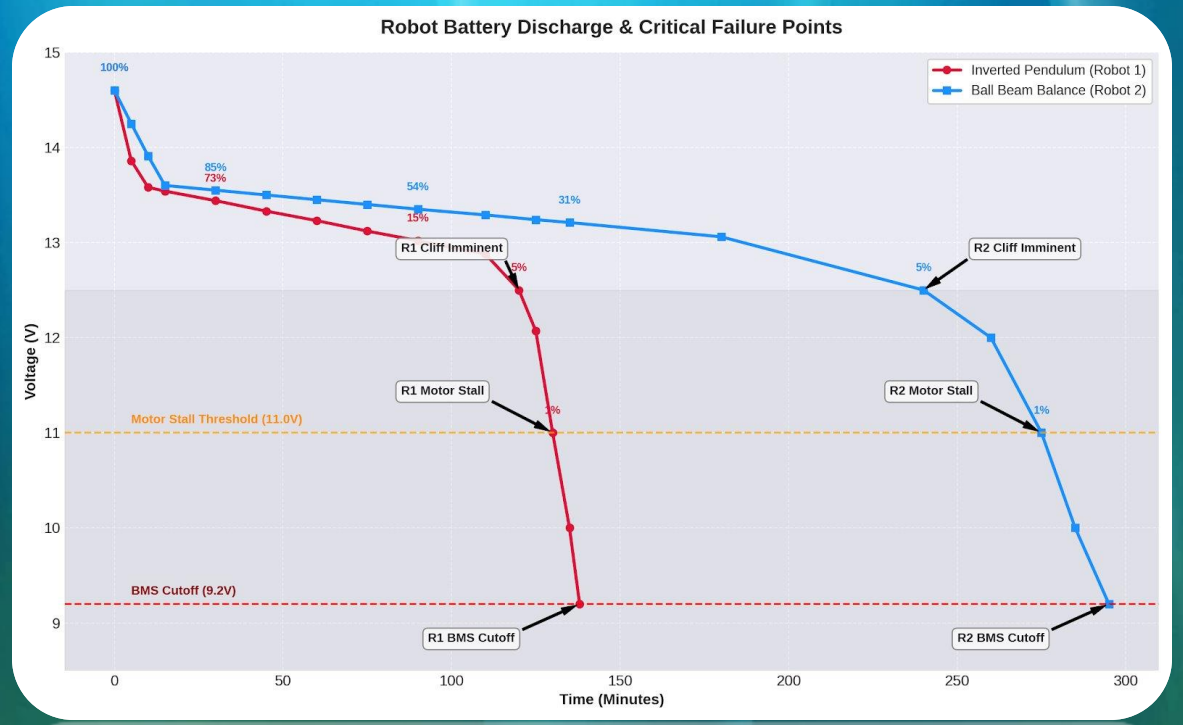
IPR

Magnetic Encoder Calibration			
Physical Angle	Raw Output	Calibrated (+56.0°)	% Error (180° FSR)
0° (Flat Left)	-54.4°	1.6°	0.89%
45°	-9.3°	46.7°	0.94%
90° (Upright Center)	34.0°	90.0°	0.00%
135°	84.0°	140.0°	2.78%
180° (Flat Right)	127.2°	183.2°	1.78%

BBBR

Time-of-Flight Sensor Calibration			
Physical Mark	Raw Reading	Calibrated (−2.3 cm)	Tracking Error
0 cm (Close End)	2.3 cm	0.0 cm	0.00%
7.28 cm (1st Quarter)	9.5 cm	7.20 cm	1.10%
14.55 cm (Middle)	17.1 cm	14.80 cm	1.70%
21.83 cm (3rd Quarter)	23.5 cm	21.20 cm	2.90%
29.10 cm (Far End)	30.2 cm	27.90 cm	4.10%

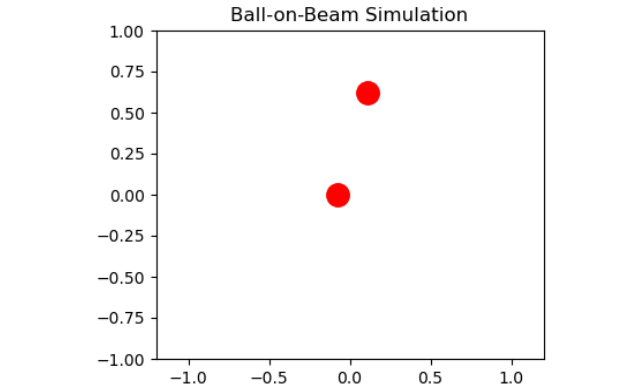
Robot Life

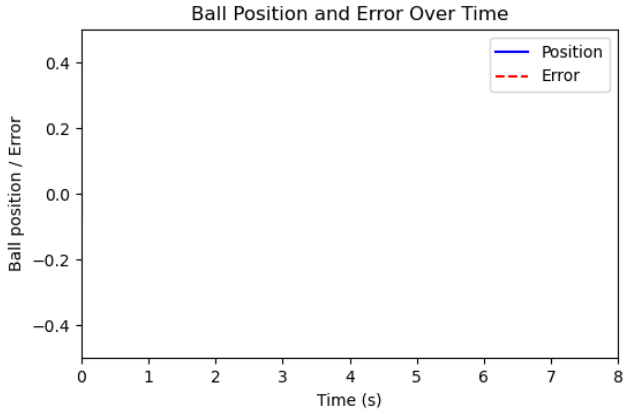


- Inverted Pendulum Robot lasts about 2 hours
- Ball Beam Balance Robot lasts about 4.5 hours
  - Theoretical measurements for both

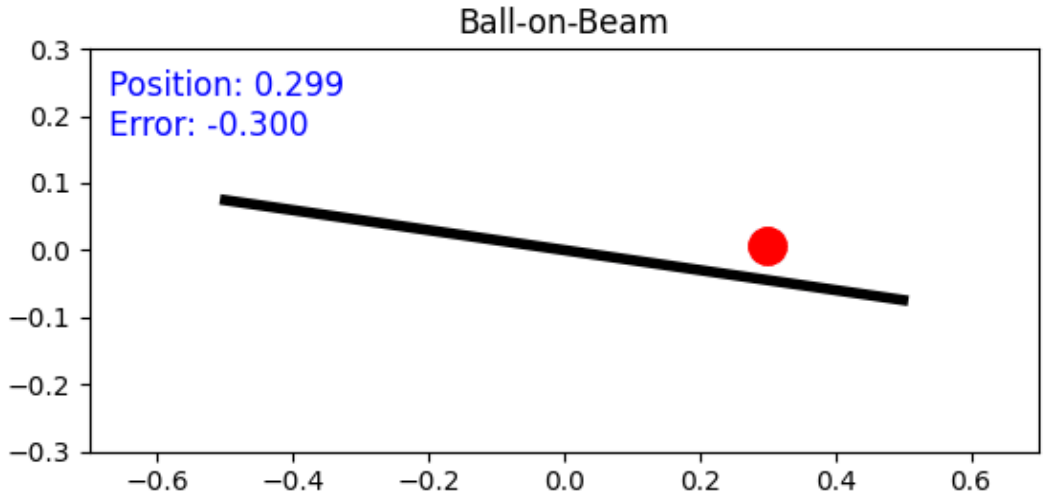
The Inverted Pendulum Robot passed the drop test with no structural issues!

Simulation





Inverted Pendulum Robot Sim



Ball Beam Balance Robot Sim

Live Demo!

Lessons Learned

- Need more testing before the robot housing got finalized
- Read all datasheets before trusting listings
- Plan workload around shipping and printing times
- Should have added more safeguards in our initial circuit designs
  - Things to prevent frying our boards etc.

Moving Forward

- Get the Inverted Pendulum Robot demonstration ready
  - Able to detect desk edges so it will not fall
  - Better wire management & support for electronics
- Implement PCB in both robots
- Mass production
- Physical demonstrations in schools

Thank You!