Motivation and Key Roles

A shared interest in bicycle design and robotics lead us to combine our talents to create a product that gets others involved in science.

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nathan Bogdonas</td>
<td>Lead Programmer</td>
</tr>
<tr>
<td>Kristen Brennan</td>
<td>Lead Analyst</td>
</tr>
<tr>
<td>Jeremy Dixon</td>
<td>Lead Manufacturer</td>
</tr>
<tr>
<td>April Kutz</td>
<td>Lead Designer</td>
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</tbody>
</table>
The Need

• Lack of interest in Science, Technology, Engineering, and Mathematics (STEM)
  – “Too hard”
  – Not enough exposure to the possibilities

• Not enough research on Reinforcement Learning
  – Unknown capabilities

• Our goal
  – To further the application of reinforcement learning to a robotic bicycle and to inspire continuous education in the process.

• Ultimately successful if more students get interested or involved in STEM
Challenges

• STEM
  – Affordable and valuable
  – Modern technology
  – Easily implemented into a classroom setting

• Q-Learning
  – Understanding bicycle dynamics
  – Find optimal balance of greedy and random actions
  – Modular algorithm
Q-Learning Basics

- Q-Learning is a form of artificial intelligence
- Uses rewards to learn optimal actions
- Must balance “greedy” and “random” actions
- Able to learn one way and then learn another
- Typically used as an optimization software
Q-Learning Algorithm Logic

Read Inputs

Lean Angle (0-60°)

- 0-10°
- 10-20°
- 20-30°
- 30-40°
- 40-50°
- 50-60°

Send Voltage to Motor

Output

0 → 0 → 0
5 → 5 → 5
10 → 10 → 10
-10 → -10 → -10
-5 → -5 → -5
0 → 0 → 0

Stored

Voltage to Motor

Read Inputs

Lean Angle (0-60°)

- 0-10°
- 10-20°
- 20-30°
- 30-40°
- 40-50°
- 50-60°

Send Voltage to Motor

Output

0 → 0 → 0
5 → 5 → 5
10 → 10 → 10
-10 → -10 → -10
-5 → -5 → -5
0 → 0 → 0

Stored
Introducing BikeBot

• Robotic bicycle that learns balanced riding
• New application to Q-Learning
• Classroom aid
  – Multidisciplinary: Mechanical, Electrical & Computer Programming
  – Hands on learning
  – Adaptable
Design

- Room for components
- Durable
- Center of mass adjustment
- Compact size for classroom use
Build

• Available Resources
  – Welder
  – Drill press
  – Pneumatic tools
  – Laser cutter

• Time Restraint
  – Off the shelf products
  – Scheduled summer meetings
Design Problems and Solutions

• Drive Train
  – Rear wheel driven

• Steering
  – Restricted steer angle
  – Attach servo motor
Design Problems and Solutions

- Training wheels
  - Switches with wheels
  - Limits lean angle

- Shelves
  - Separate components
  - Position IMU near pivot point
Simulation

• Why the simulation is needed
  – Test and verify algorithm virtually
  – Time saving
  – Provides unsupervised learning

• Easy way to face new challenges
  – Reaching a destination
  – Avoid obstacles
  – Varying speed
Simulation

• How the simulation was created
  – System modeled as inverted pendulum
  – Restoring moment to keep lean angle within physical range

• Ideal outcome
  – Lean angle $\phi$ and its rate of change $\dot{\phi}$
  – Steer angle $\delta$
  – Convergence: $(\phi, \dot{\phi}, \delta) \rightarrow (0, 0, 0)$
Testing & Results

• Q-Learning with the simulation
  – Live plotting of state space
  – Several plots with changing parameters
    • Number of iterations (1 iteration = 20 milliseconds)
    • Type of reward system
    • Deciding factors for action taking
Lean Angle vs. its Rate of Change

→ 10,000 iterations, 100% random action taking
Lean Angle vs. its Rate of Change

→ Last 10,000 of 50,000 iterations, ramp reward system
Testing & Results

Lean Angle vs. its Rate of Change

→ Last 10,000 of 50,000 iterations, top & bottom reward system
Testing & Results

Lean Angle vs. its Rate of Change

→ Last 20,000 of 200,000 iterations, ramp reward system
Testing & Results

⟶ 50,000 vs. 200,000 iterations
Lean Angle vs. its Rate of Change

→ Last 1000 of 100,000 iterations, ramp reward system
Marketability

- 1100 U.S. universities with engineering programs
- ABET accreditation fulfillments
  - A: Ability to apply science and engineering
  - B: Ability to design and conduct experiments
  - D: Work in a team
  - I: Recognize the need for and engage in life-long learning
  - K: Ability to use Engineering skills, techniques, and tools
Manufacturing Considerations

• Material Cost
  – Current: $221.00
  – Desired: $175.00
    • 20% reduction

• Ways to reduce cost
  – Plastic molded frame
    • Acetal
  – Off the shelf parts in bulk
    • Reduces price per unit

• Revenue
  – Target price $350.00
  – 25% of universities
  – Estimated $275,000.00

<table>
<thead>
<tr>
<th>Estimated Cost</th>
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<tbody>
<tr>
<td><strong>Raw Materials</strong></td>
<td></td>
</tr>
<tr>
<td>Sheet Metal</td>
<td>$12.00</td>
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<tr>
<td>Brake Tube</td>
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<tr>
<td><strong>Hardware</strong></td>
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<tr>
<td>Ball Bearings</td>
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<tr>
<td>Miscellaneous</td>
<td>$11.00</td>
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<tr>
<td>Wires</td>
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<tr>
<td><strong>Parts</strong></td>
<td></td>
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<tr>
<td>Raspberry Pi</td>
<td>$36.00</td>
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<tr>
<td>Motors</td>
<td>$42.00</td>
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<tr>
<td>IMU</td>
<td>$43.00</td>
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<tr>
<td>Chain and Sprockets</td>
<td>$23.00</td>
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<tr>
<td>Wheels</td>
<td>$8.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$221.00</td>
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BikeBot in Action