# Self-Balancing Bike

Philip Salmony, Wolfson College

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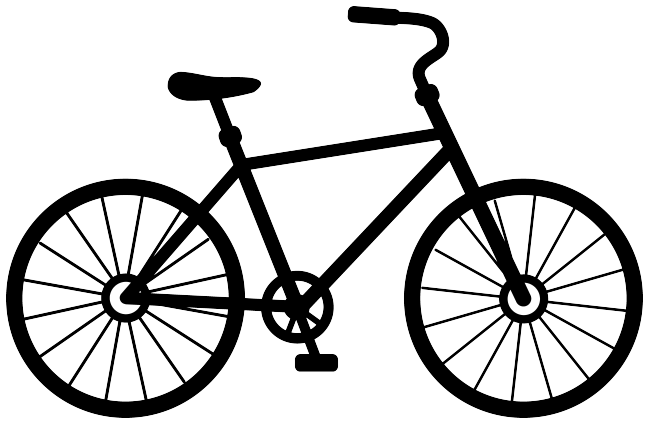


# Background and Context

- Bicycle stability and equations of motion studied for well over 100 years.
  - e.g., Whipple (1899), Papadopoulos (1980s), Astrom (2005)
- Still misconceptions about why a bike is self-stable.
- "Inverted pendulum"
- Under-actuated system

**"Everybody knows how to ride a bike, but no one knows how we ride bikes."**

# Aims and Significance

- How does a human stabilise a bicycle?
- What makes a bicycle more or less stable?
- Can we design a control algorithm that stabilises a bicycle in **all** situations?

**Generally, an interesting but rather difficult control problem!**

# Honda Self-Balancing Bike

*Source: https://motorbikewriter.com/honda-self-balancing-bike-electric/*

October 2017 - **not very long ago!**

# Progress - Modelling

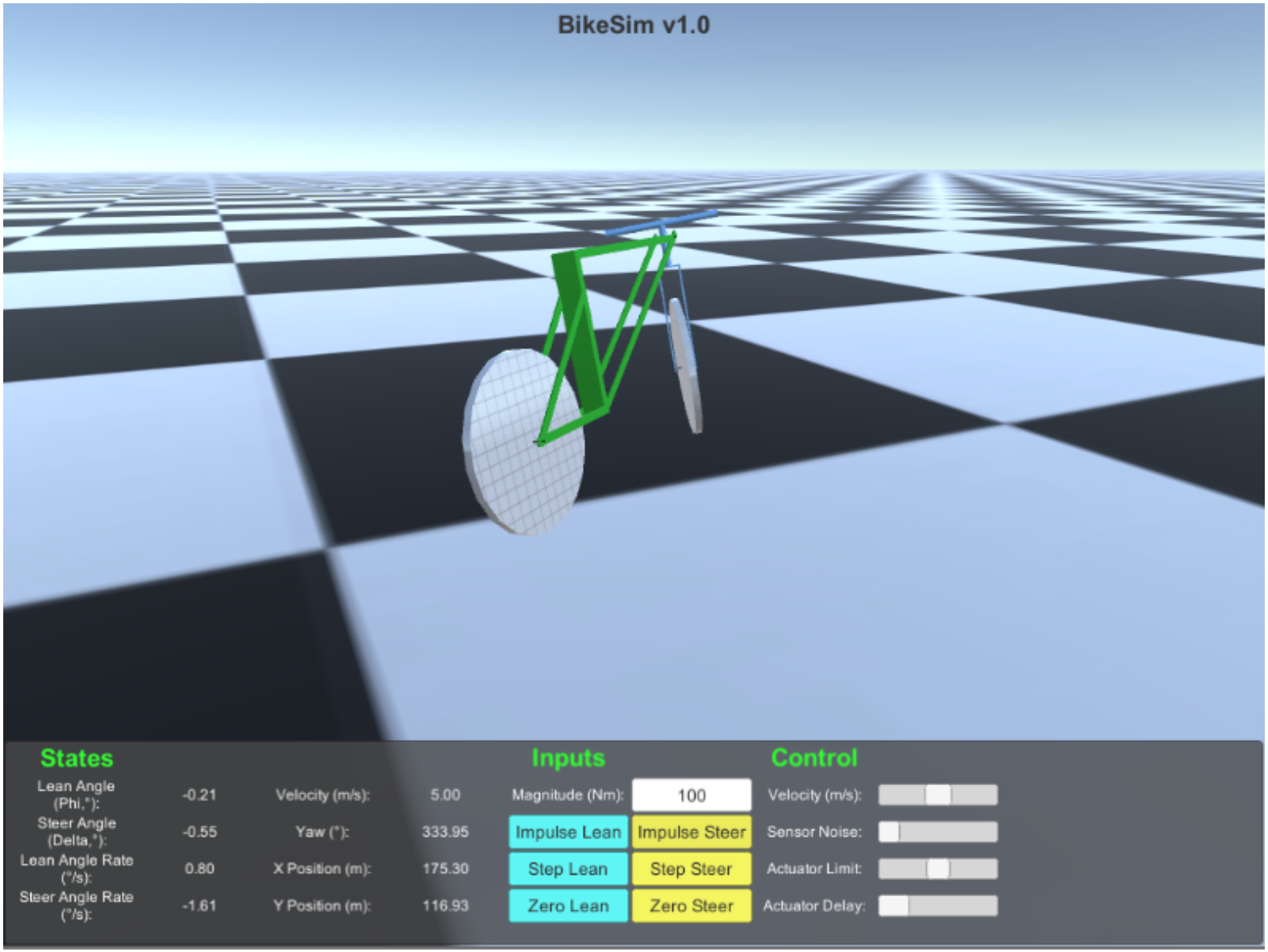
- **Linear and non-linear bicycle models** for simulation
  - Many, very complex and coupled non-linear, differential equations.
  - Fourth-order linearised model, dependent on forward speed:

$$\mathbf{M} \cdot \underline{\ddot{q}} + \mathbf{C}_1 \cdot v \cdot \underline{\dot{q}} + (\mathbf{K}_0 + \mathbf{K}_2 v^2) \cdot \underline{q} = \begin{bmatrix} 0 \\ \tau \end{bmatrix}$$

- **Stability investigation**

- Developed **simulations** in Unity and MatLAB/Simulink

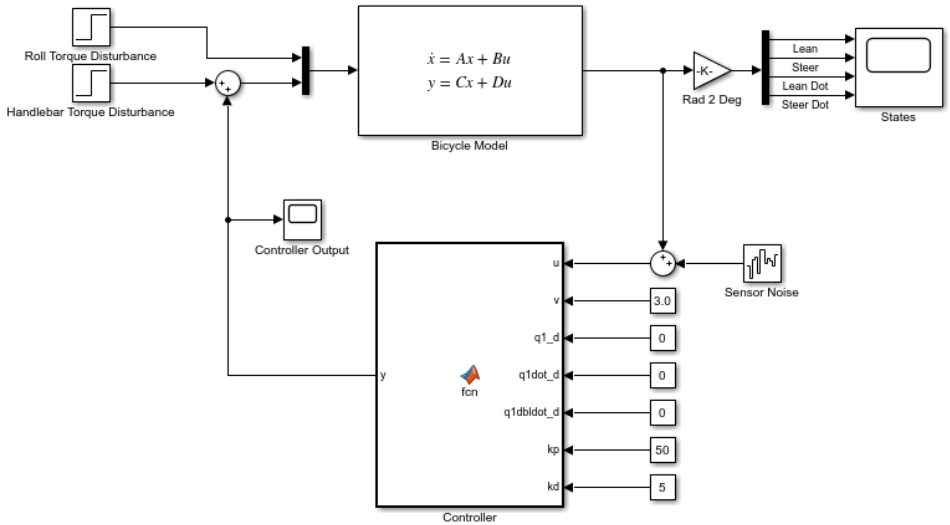
# Progress - Simulations (Unity)

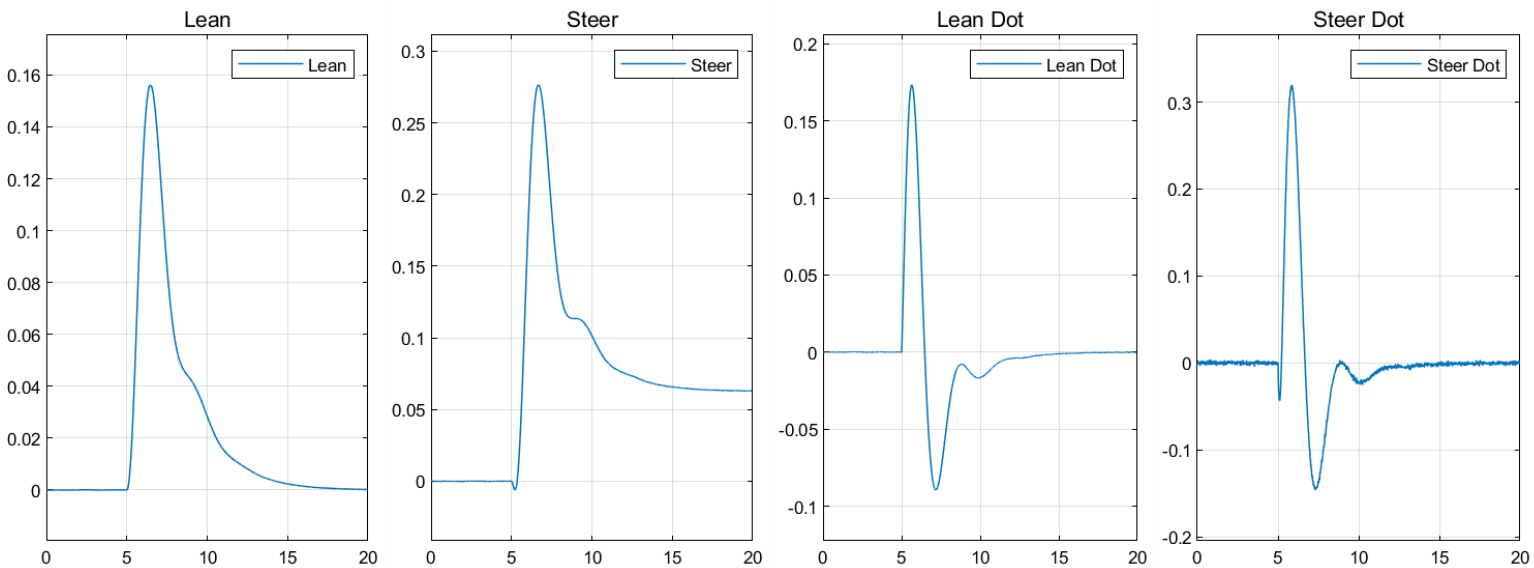


# Progress - Controller Design

- Investigated **linear PD and LQR** controller design
  - Limitation: need several controllers to cope with varying speeds!
- Developed **LEGO Mindstorms prototype** ▸ Video
- Looked into **non-linear control**
  - Desire a **single** controller that works across **all** speeds.
  - Virtual Model Control
  - Energy-Balancing Control: *Putting Energy Back in Control, R. Ortega et al.*

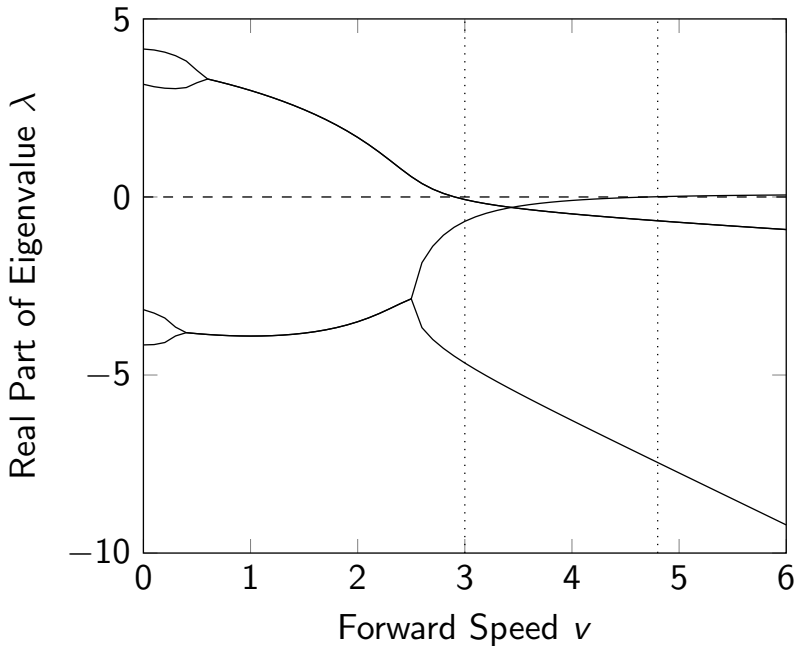
# Progress - Controller Design (PD)



# Findings So Far I

- *Modelling and Simulation*
  - Non-linear model too hard to interpret intuitively.
  - Stability *strongly* dependent on forward speed.
  - Difficult system: RHP poles and zeros
- *Linear Control*
  - In theory, PD and LQR controllers can stabilise a rider-less bicycle.



# Findings So Far II

- *Non-linear Control*
  - Virtual Model Control: need little knowledge about system, works in theory.
  - Energy-Balancing Control: finding re-shaping controller gets more and more difficult as system complexity increases.
- *Key Problems*
  - Model identification
  - Real-world implementation
- *Full-scale Bike*
  - A lot of work...
  - Sourcing components, mechanical design
  - Scaling-up of controller design

# Plans

- **Michaelmas**
  - Improve LEGO prototype.
  - Further investigate non-linear control.
- **Lent**
  - $H_\infty$ loop shaping for robust control.
  - Trajectory tracking.
  - Move on to *full scale bike*!

# Questions

**Thanks for listening!**

Any questions?