First Look at Rider Biomechanics while Controlling a Bicycle

Reverend Jason K. Moore

Bicycle Dynamics Lab
3mE/PME Engineering Dynamics
Delft University of Technology
&
Sports Biomechanics Lab
Mechanical and Aeronautical Engineering Department
University of California, Davis

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Introduction
- Handling Qualities
- What do we know?
- What we want to know

Instrumented bicycle
- The bicycle
- Experiments
- Conclusions

Motion Capture
- Experiments
- Data Processing
- Results

Conclusions

The Holy Grail

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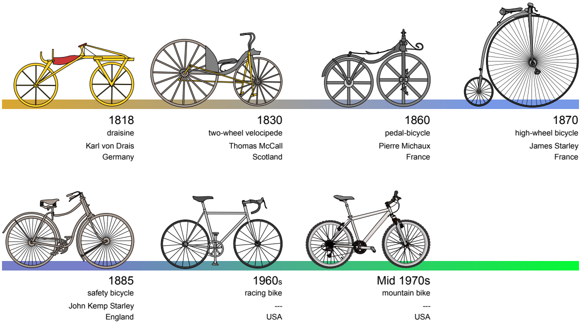
- What are we seeking?
  - To be able to predict the handling qualities of a bicycle.
- What is a handling quality?
  - A measure that determines the ease and precision with which a rider may complete a given task

But why?

Isn't the bicycle perfect the way it is?



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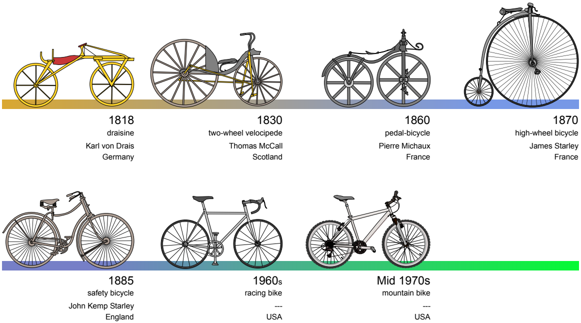

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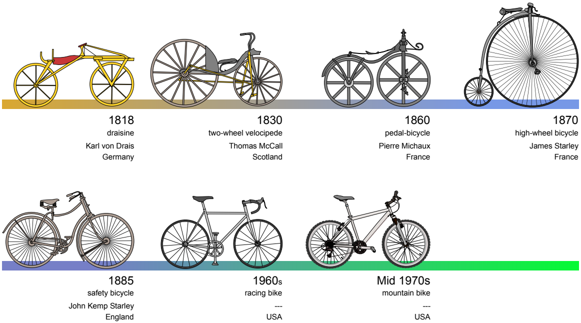

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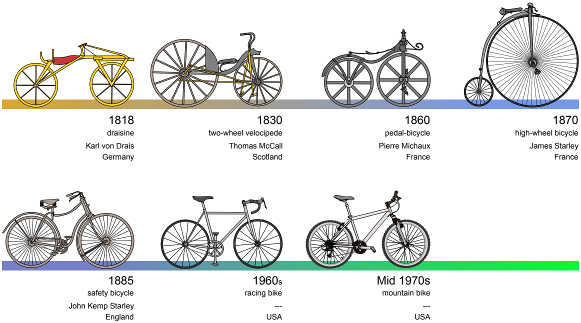
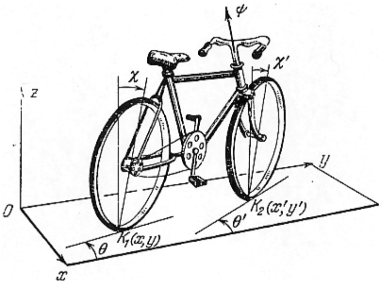
- The bicycle evolved from 200 years of tinkerers.
- Alternative designs do not have this luxury.
- Help shed light on many other human/machine interactions.



Handling qualities road map

Vehicle Dynamics
↓
Human Biomechanics
↓
Manual Control
↓
Handling qualities



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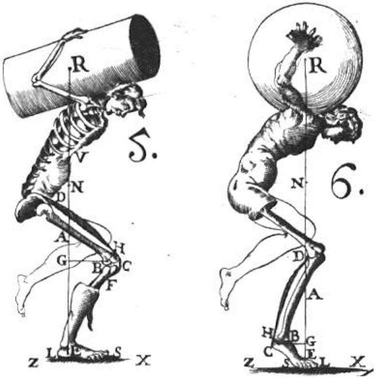

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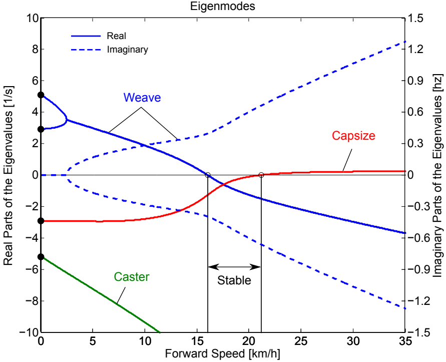
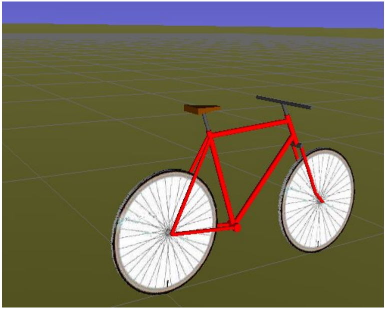
We only confidently know two things about bicycle dynamics:

- Fact # 1: Some bicycles are stable at various speeds.
- Fact # 2: Steering into the lean will stabilize the bicycle. As a consequence, to go right you have to steer to the left!

Unstable at 0 km/h

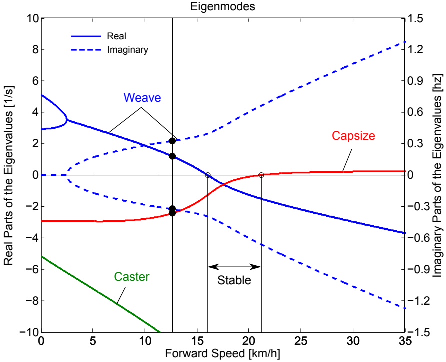


Linear model



Non-linear simulation

Unstable 12.6 km/h



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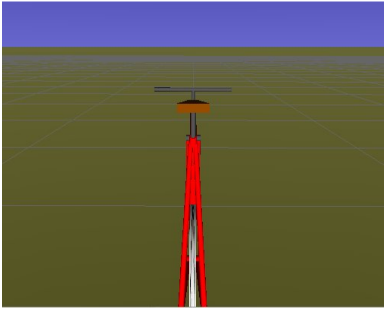
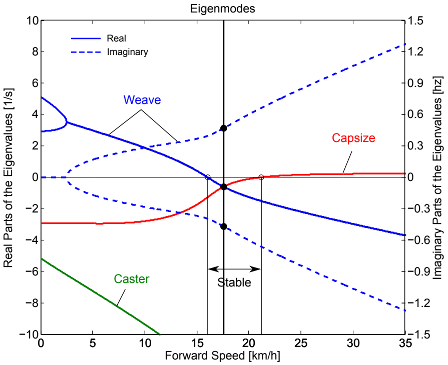


Non-linear simulation

Stable at 17.6 km/h



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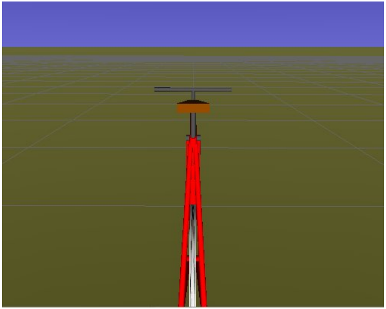
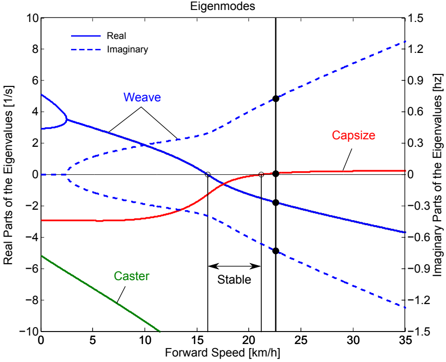


Non-linear simulation

Unstable at 22.7 km/h



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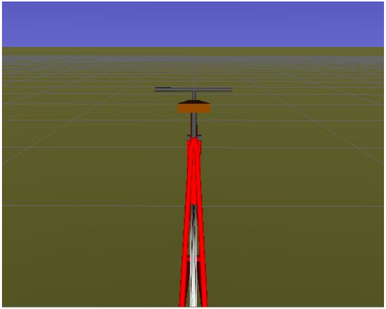

Non-linear simulation

Yellow Bicycle

Gyrobike

Countersteering

Vehicle dynamics and handling

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- Stability does not necessarily equate to ease of control
- Are the uncontrolled dynamics and indicator of handling?
  - For aircraft, connections have been found
  - Unlike a bicycle, the pilot's motion does not affect the aircraft's dynamics
  - Pilot and manual control theory have provided more insight

How do we control the bicycle?

Danny MacAskill, Pro Trials Rider

How do we control the bicycle?

Obvious control input candidates:

Not so obvious candidates:

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Obvious control input candidates:

- Steering

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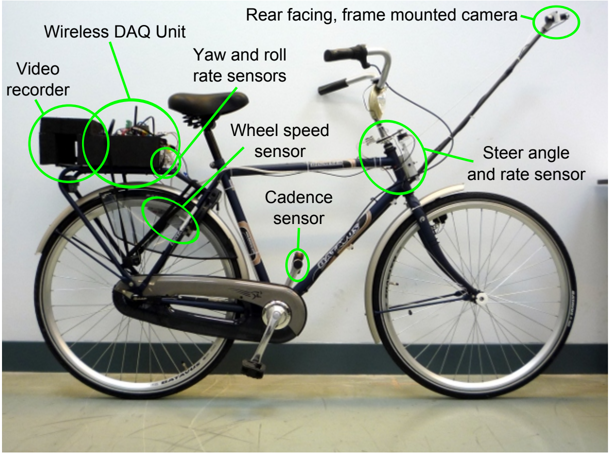
First step: objectively observe and measure what the rider does

The bicycle


Rear facing, frame mounted camera
Wireless DAQ Unit
Video recorder
Yaw and roll rate sensors
Wheel speed sensor
Steer angle and rate sensor
Cadence sensor

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- Treadmill tests: pedaling, no pedaling, no-hands, perturbing, lane change
- Measured bicycle dynamics and observed rider

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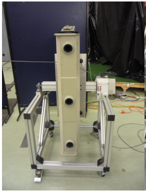
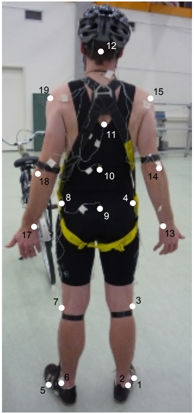
But, no easy way to quantify the rider's movements.

Experimental Setup

- Full body motion capture with active markers
- Two different bicycles and three adult male riders
- Treadmill tests (pedaling, no pedaling, no-hands, tracking) at different speeds





Principal component analysis

$$3 \text{ riders} \times 90 \frac{\text{runs}}{\text{rider}} \times 560,000 \frac{\text{data points}}{\text{run}} = 150 \cdot 10^6 \text{ data points}$$

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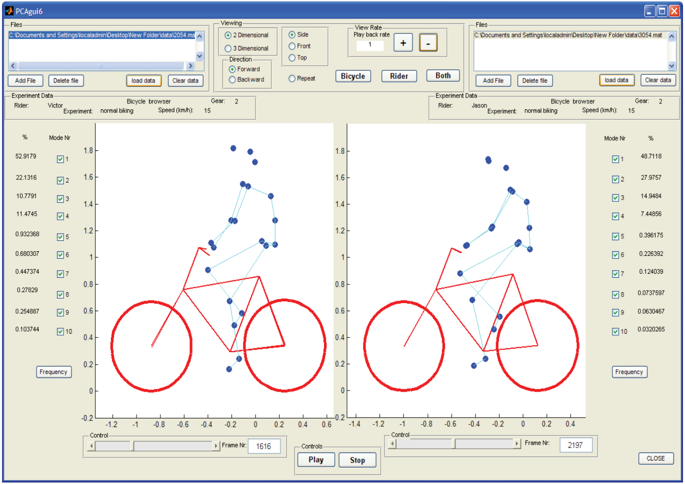
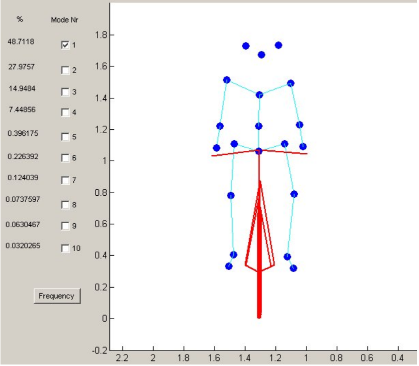
Principal Component Analysis!

- Statistical data reduction technique based on an eigenanalysis of data variance
- Used for face recognition, data compression, characterizing human walking
- Largest eigenvalue corresponds to largest variance in motion

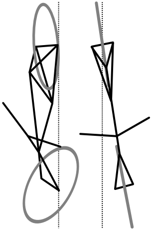
Graphical User Interface



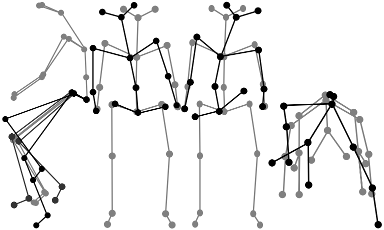
Normal bicycling at 15 km/h



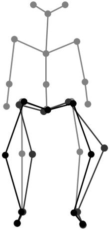
Motions and Groups



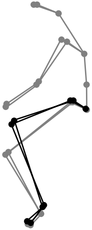
Steer-Roll-Yaw Group



Pedaling Group

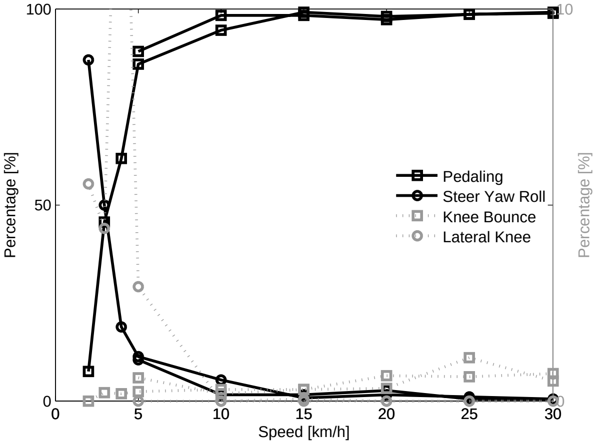


Lateral Knee Group

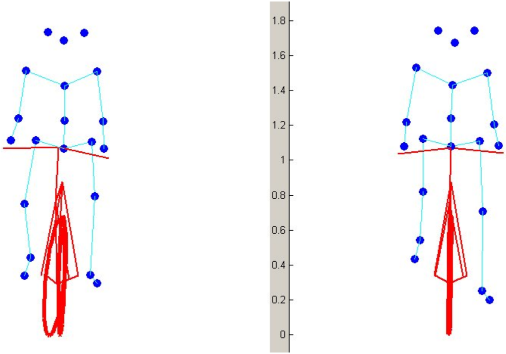


Knee Bounce Group

Group variance vs speed



Normal bicycling at 5 km/h and 25 km/h



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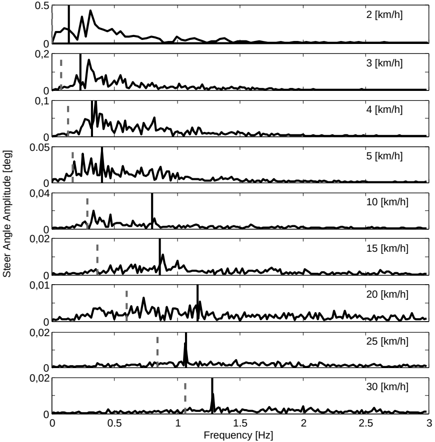
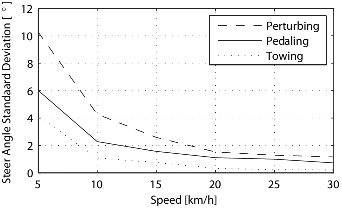
Steer angle comparisons





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- When pedaling at low speed we observe lateral knee motions which are probably also used for control.

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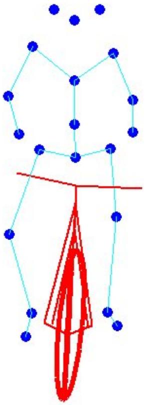
Bicycles present a rich complex and robust system to study

- vehicle dynamics (rolling contacts, variable stability)



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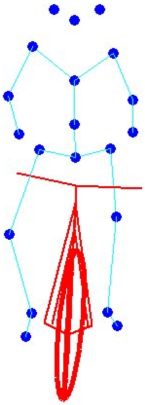

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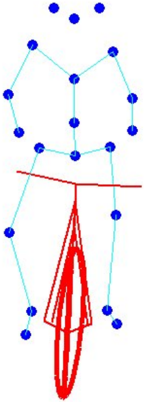

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- handling qualities (perception, psychology)