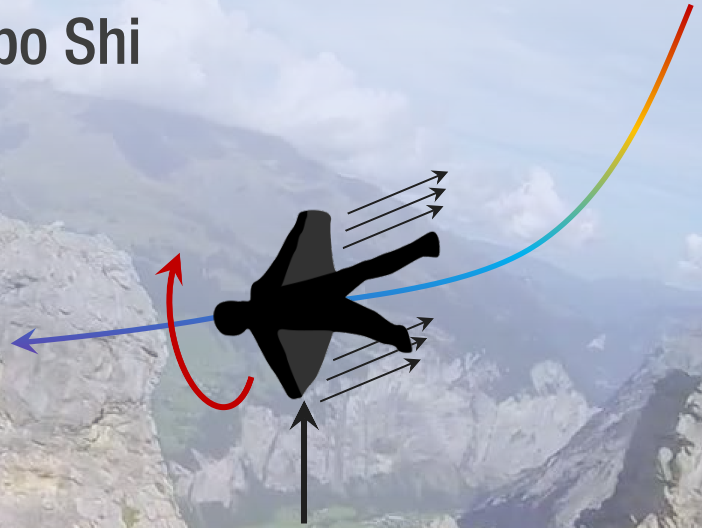
Force from Motion:
Decoding Physical Sensation from a First Person Video

Hyun Soo Park, Jyh-Jing Hwang, and Jianbo Shi

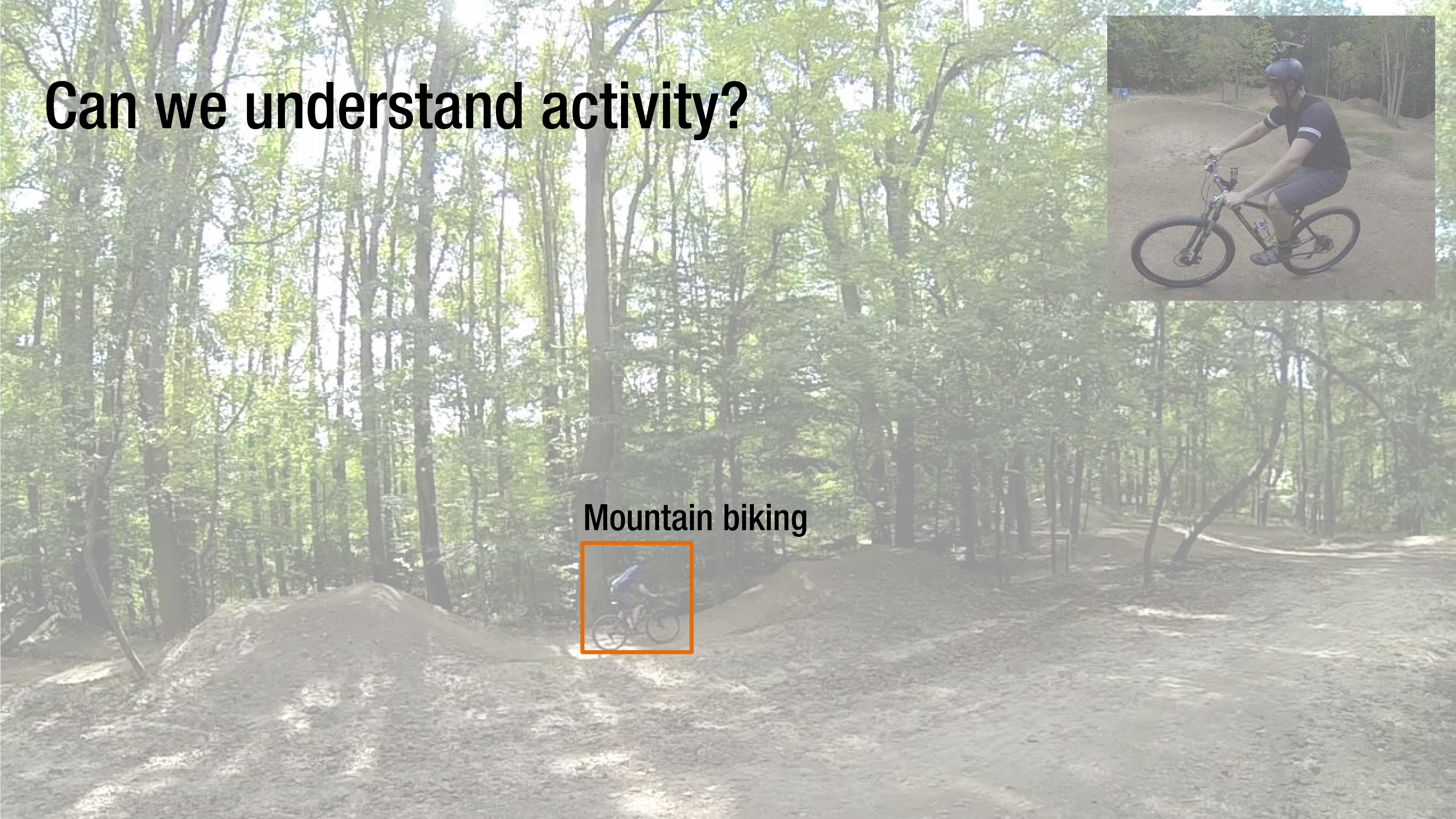
Penn



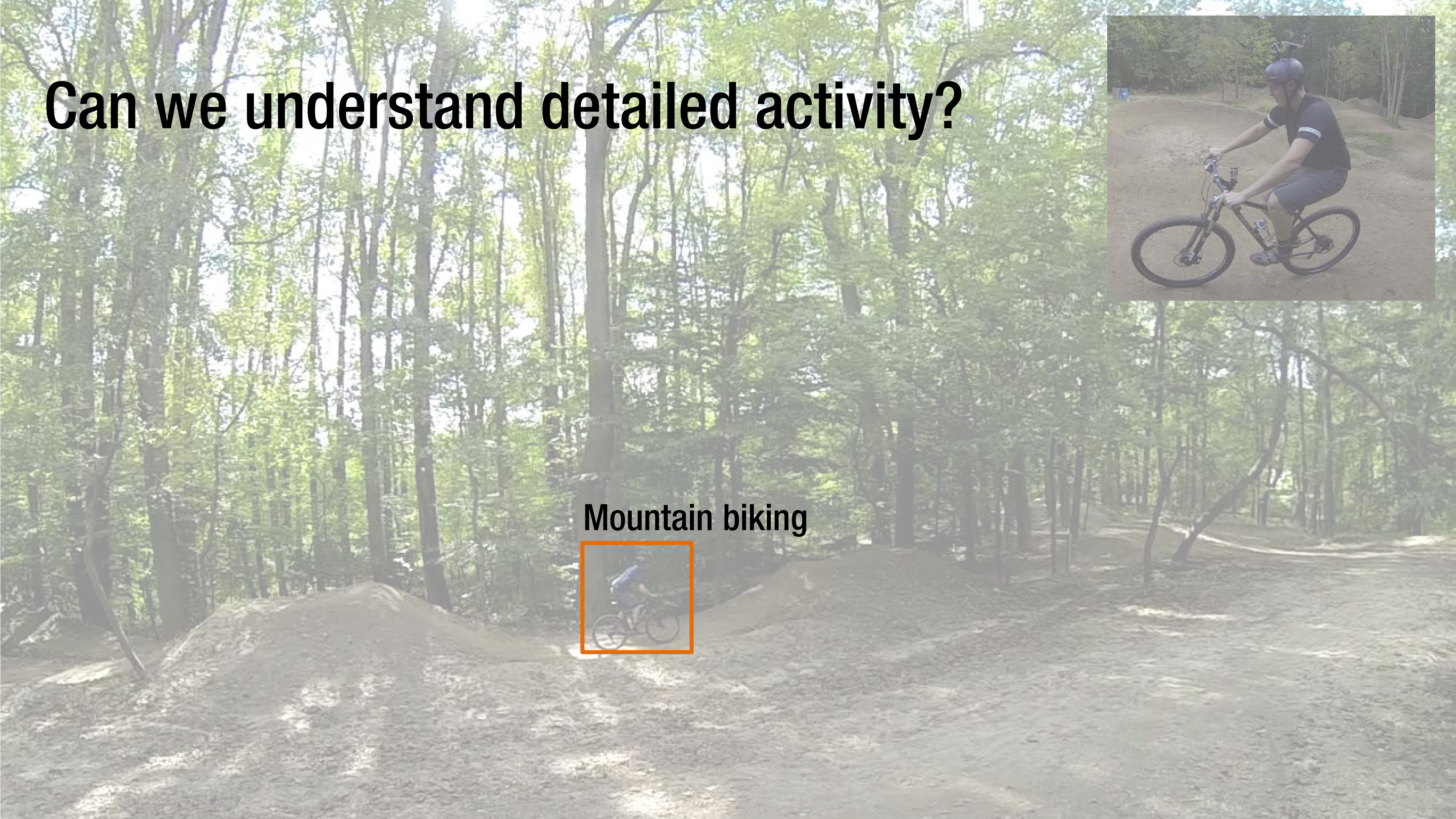

Biker


Biker

Can we understand activity?



Can we understand detailed activity?



Can we understand physics of activity?

Can we understand physics of activity?

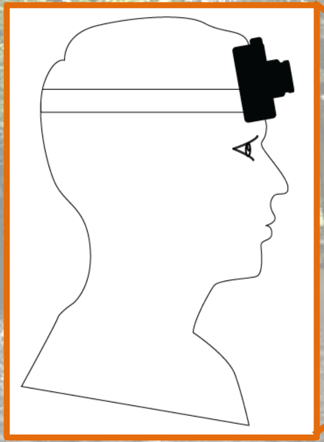
Can we understand physics of activity?

Pedaling

Braking

3. Control

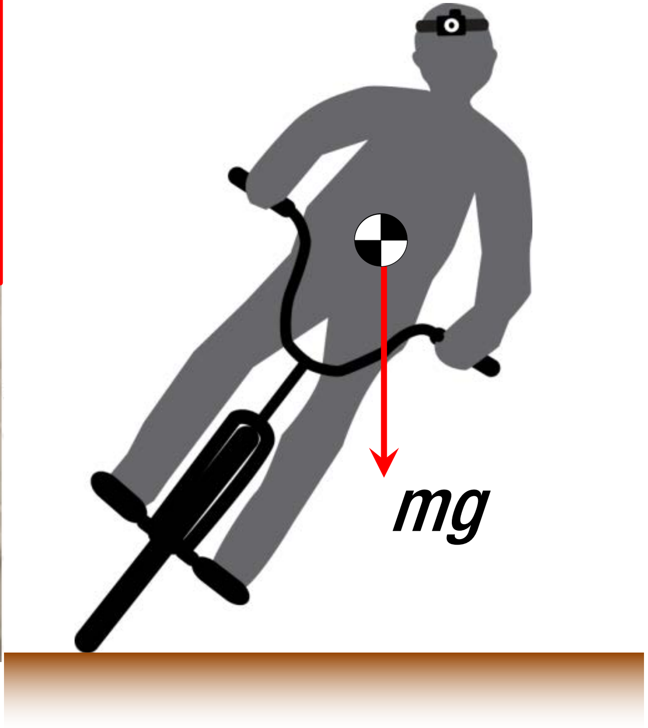
Can we understand <u>physics</u> of activity?



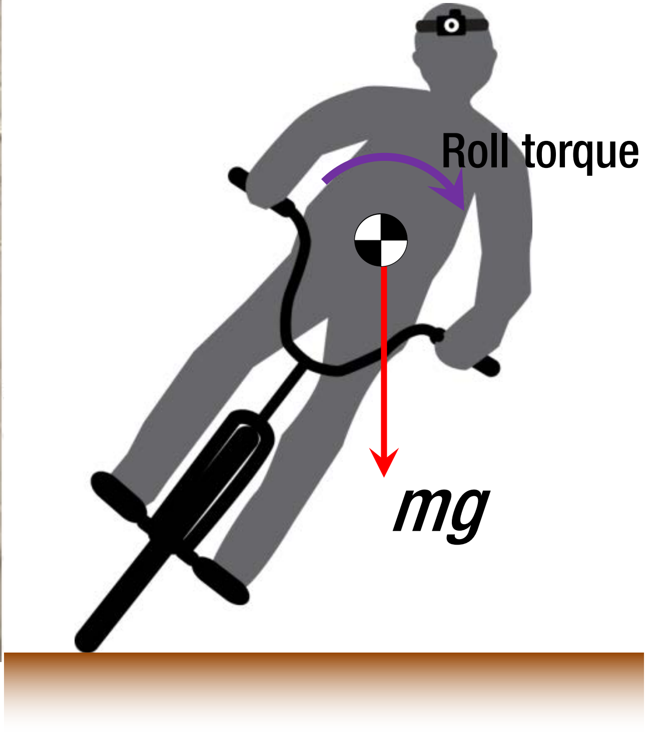
First person camera


Time: 0.17sec
Speed: 2.0m/s
Air Drag: 1.77N
Gravity
Th: -177N
Ro: 91Nm
Pi: -93Nm
Lt: 4N
No: -842N
Yw: 13Nm


Time: 0.17sec
Speed: 2.0m/s
Air Drag: 1.77N
Gravity
Th: −177N
Ro: 91Nm
Pi: −93Nm
Lt: 4N
No: −842N
Yw: 13Nm


mg

Time: 0.17sec
Speed: 2.0m/s
Air Drag: 1.77N
Gravity
Th: −177N
Ro: 91Nm
Pi: −93Nm
Lt: 4N
No: −842N
Yw: 13Nm

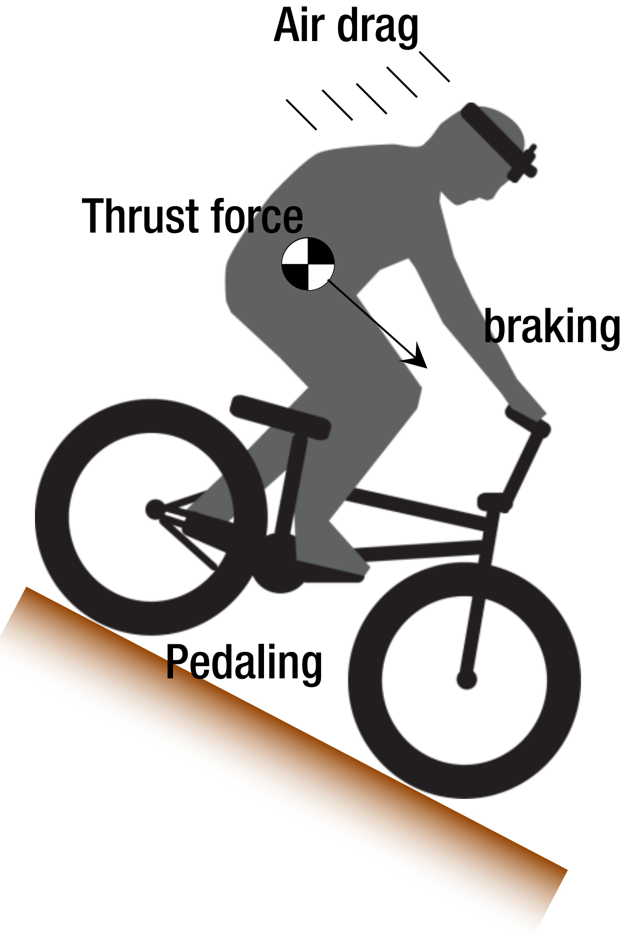


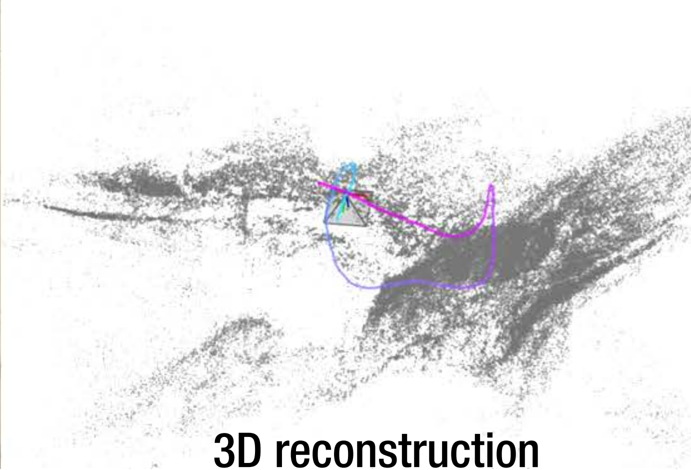
Roll torque
mg

Time: 0.17sec
Speed: 2.0m/s
Air Drag: 1.77N
Gravity
Th: -177N
Ro: 91Nm
Pi: -93Nm
Lt: 4N
No: -842N
Yw: 13Nm

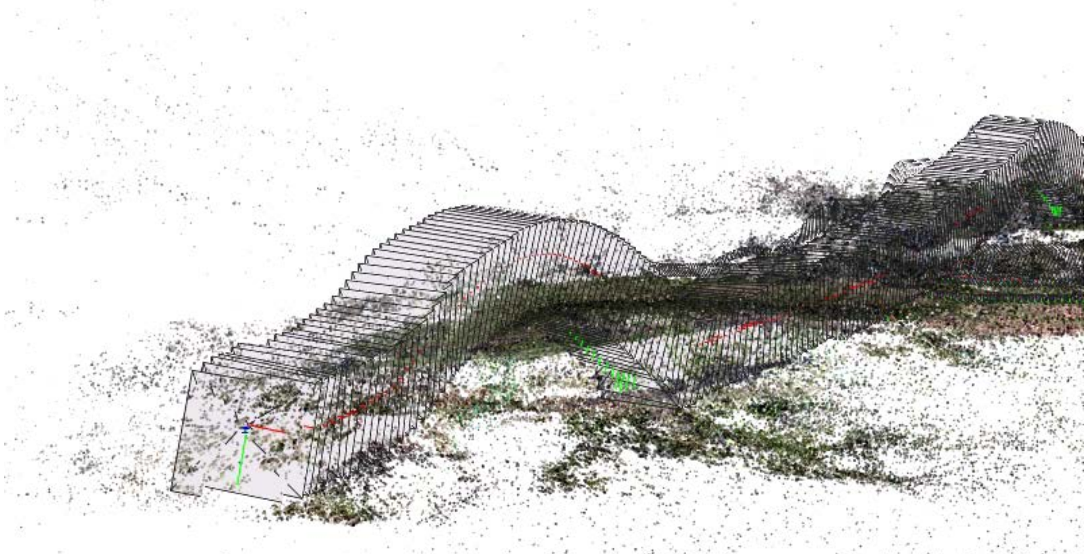
Thrust force
braking
Pedaling


Time: 0.17sec
Speed: 2.0m/s
Air Drag: 1.77N
Gravity
Th: -177N
Ro: 91Nm
Pi: -93Nm
Lt: 4N
No: -842N
Yw: 13Nm

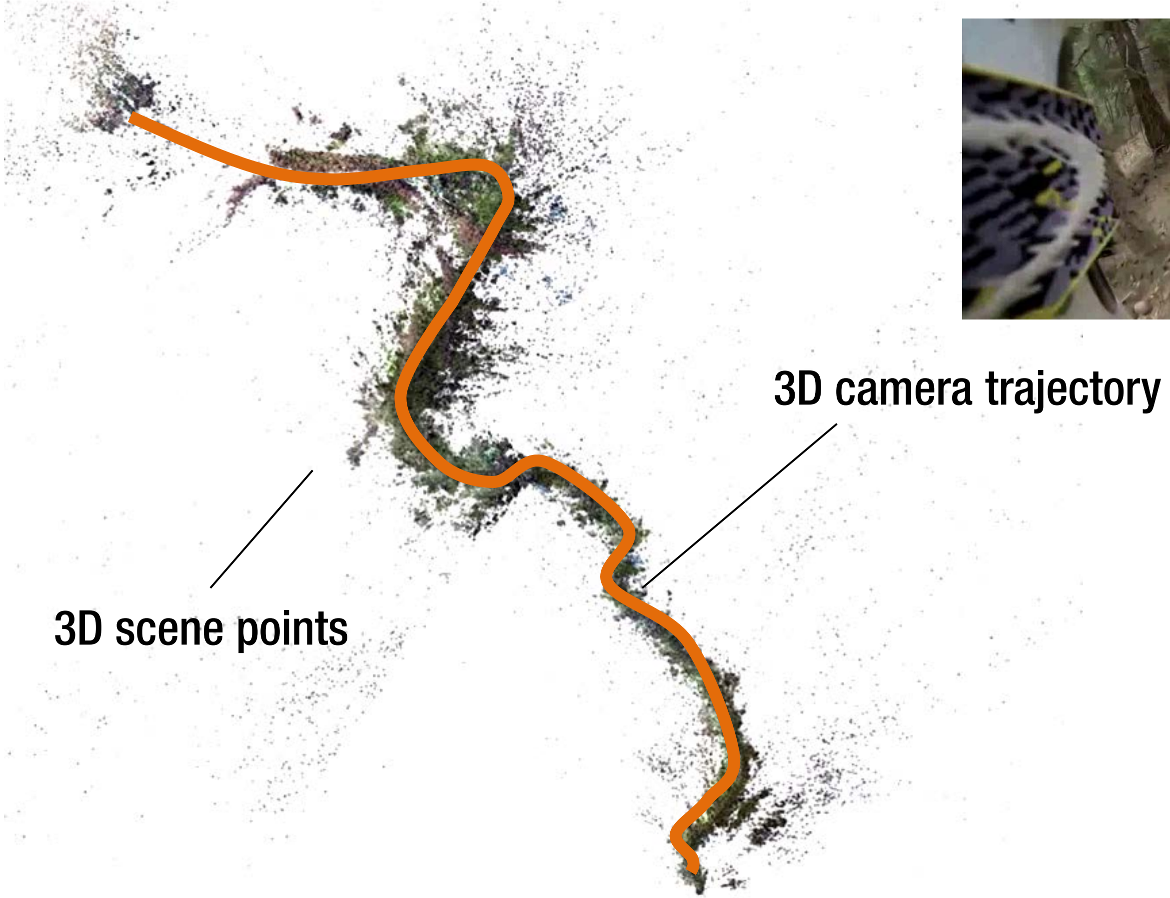

Air drag
Thrust force
braking
Pedaling



3D reconstruction



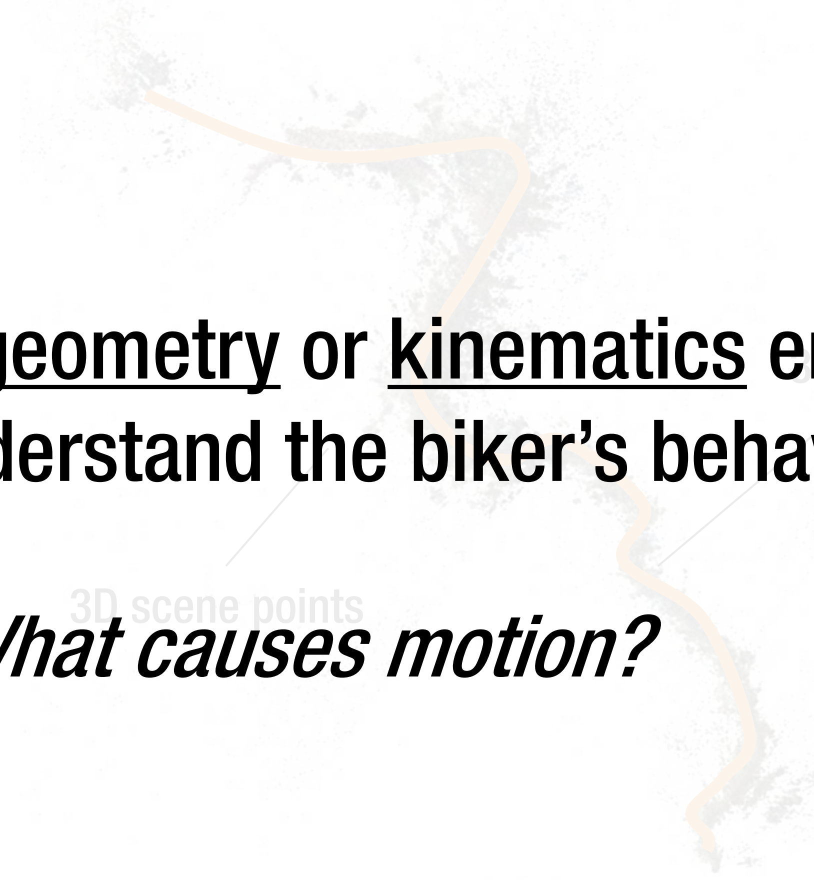
3D reconstruction



3D reconstruction

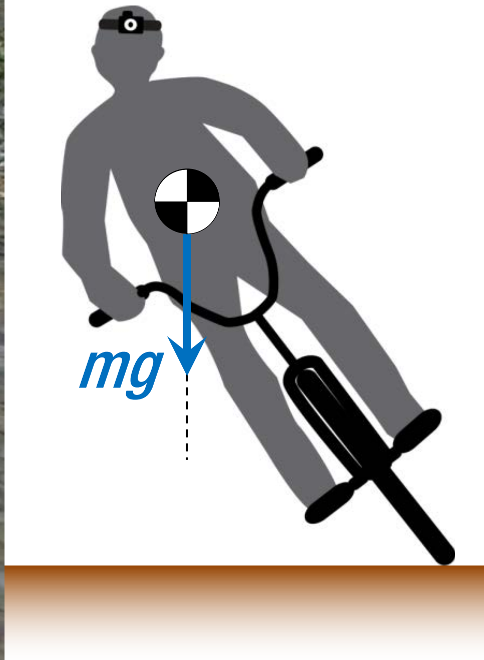
Is geometry or kinematics enough to understand the biker’s behaviors?

What causes motion?



3D reconstruction

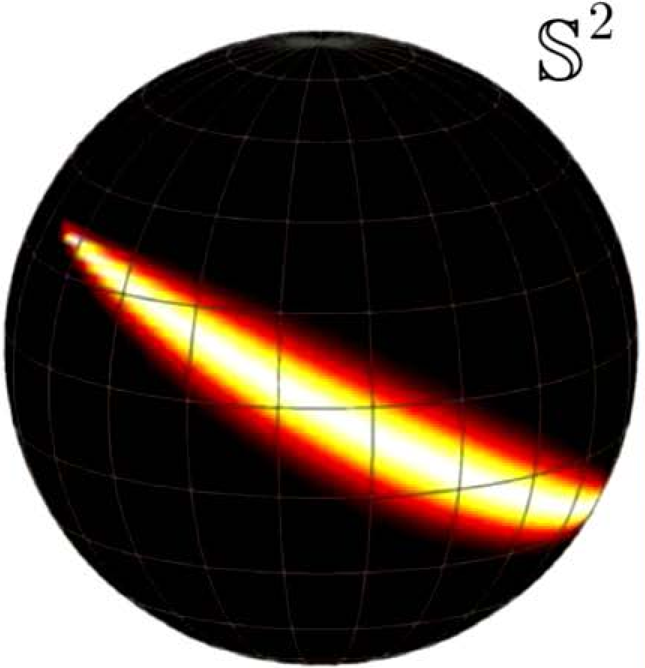
1. Compute Gravity




Tree
Water
Horizon

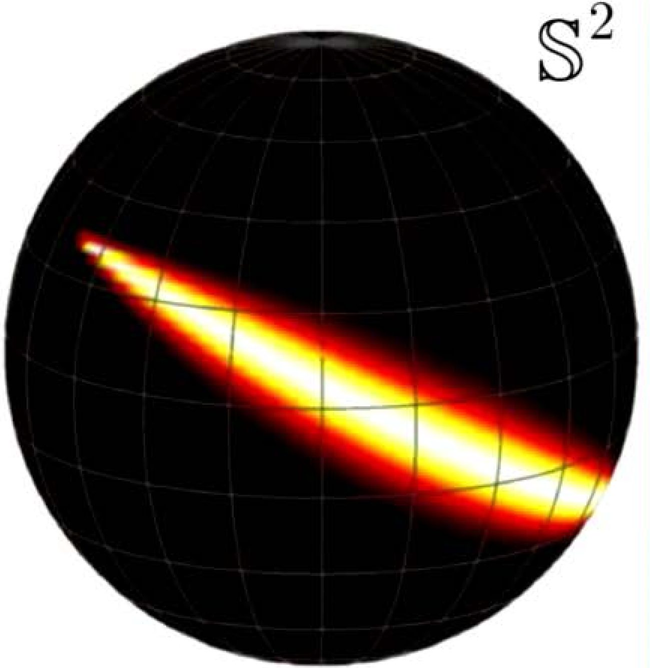

$p(\mathrm{g} \mid \mathcal{I})$
Prediction via CNN
Ground truth
Prediction error: 0.5 degree

$p(\mathcal{I} \mid \mathbf{g})$



Probability of gravity direction in 3D

Visual Gravity Prediction



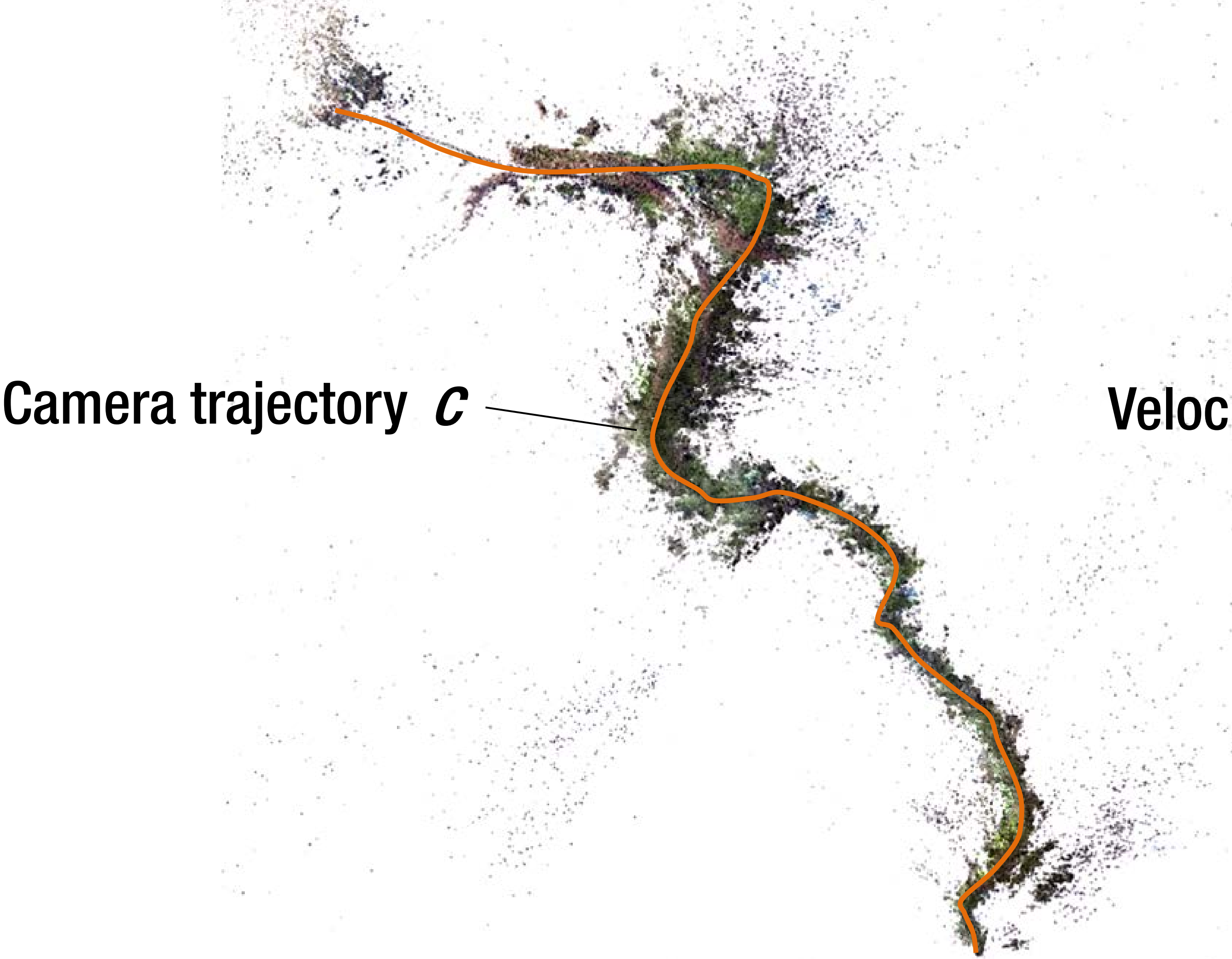
Probability of gravity direction in 3D

$$p(\hat{g} \mid \mathcal{I}_1, \cdots, \mathcal{I}_N) \propto p(\hat{g}) \prod_i^N p(\mathcal{I}_i \mid \hat{g})$$

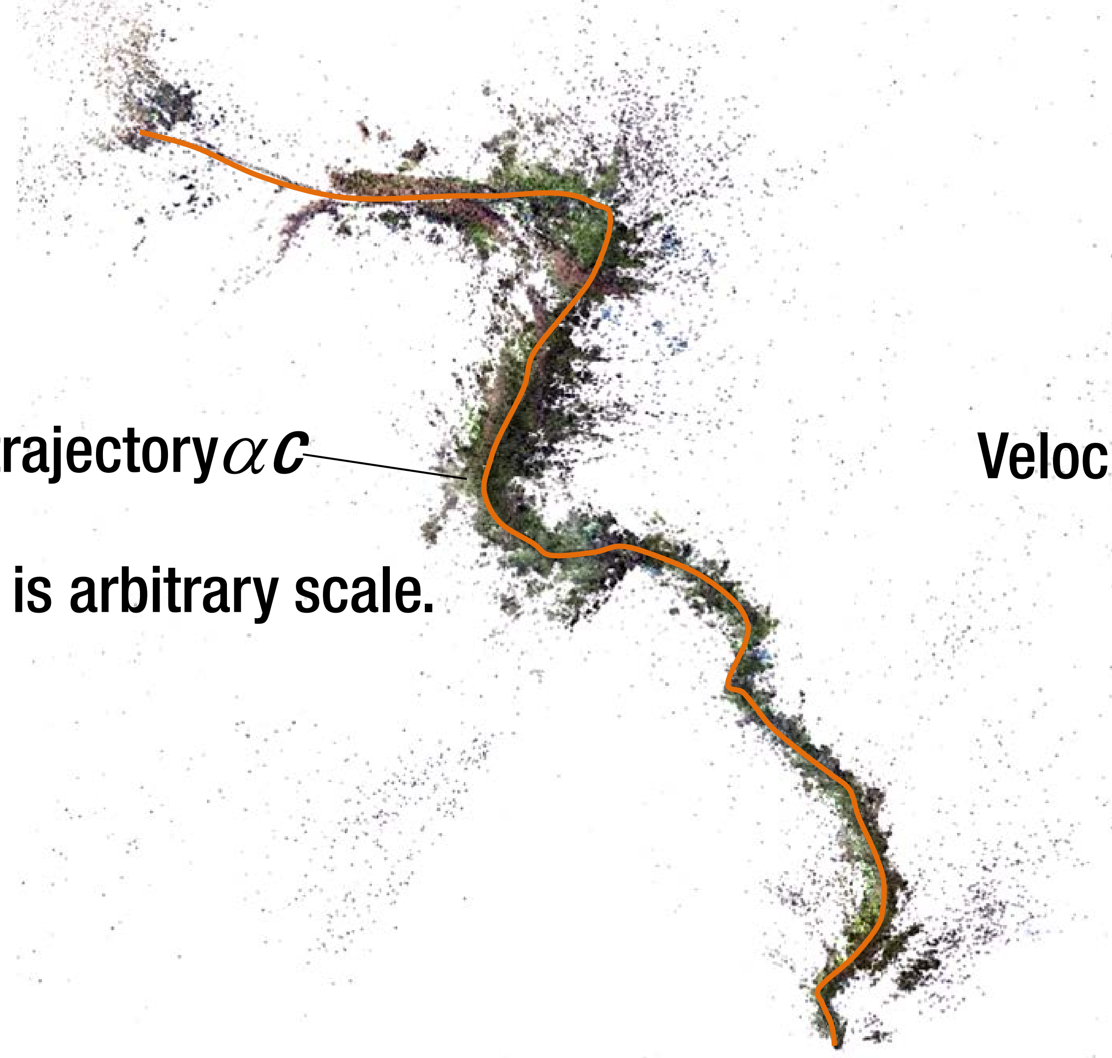

mg


mg


2. Compute Speed
m v2/r
mg



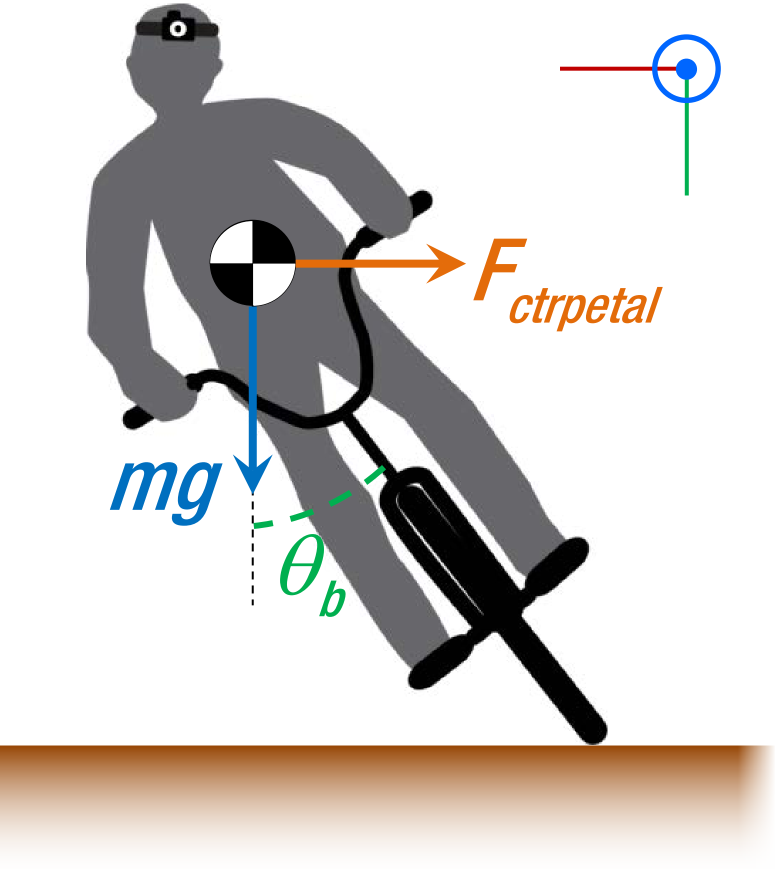
Velocity: $v = \frac{\mathrm{d}c}{\mathrm{d}t}$



Camera trajectory $\alpha \boldsymbol{c}$

where α is arbitrary scale.

Velocity: $\boldsymbol{v} = \alpha \dfrac{\mathrm{d}\boldsymbol{c}}{\mathrm{d}t}$



Banked turn

Dynamic balance:

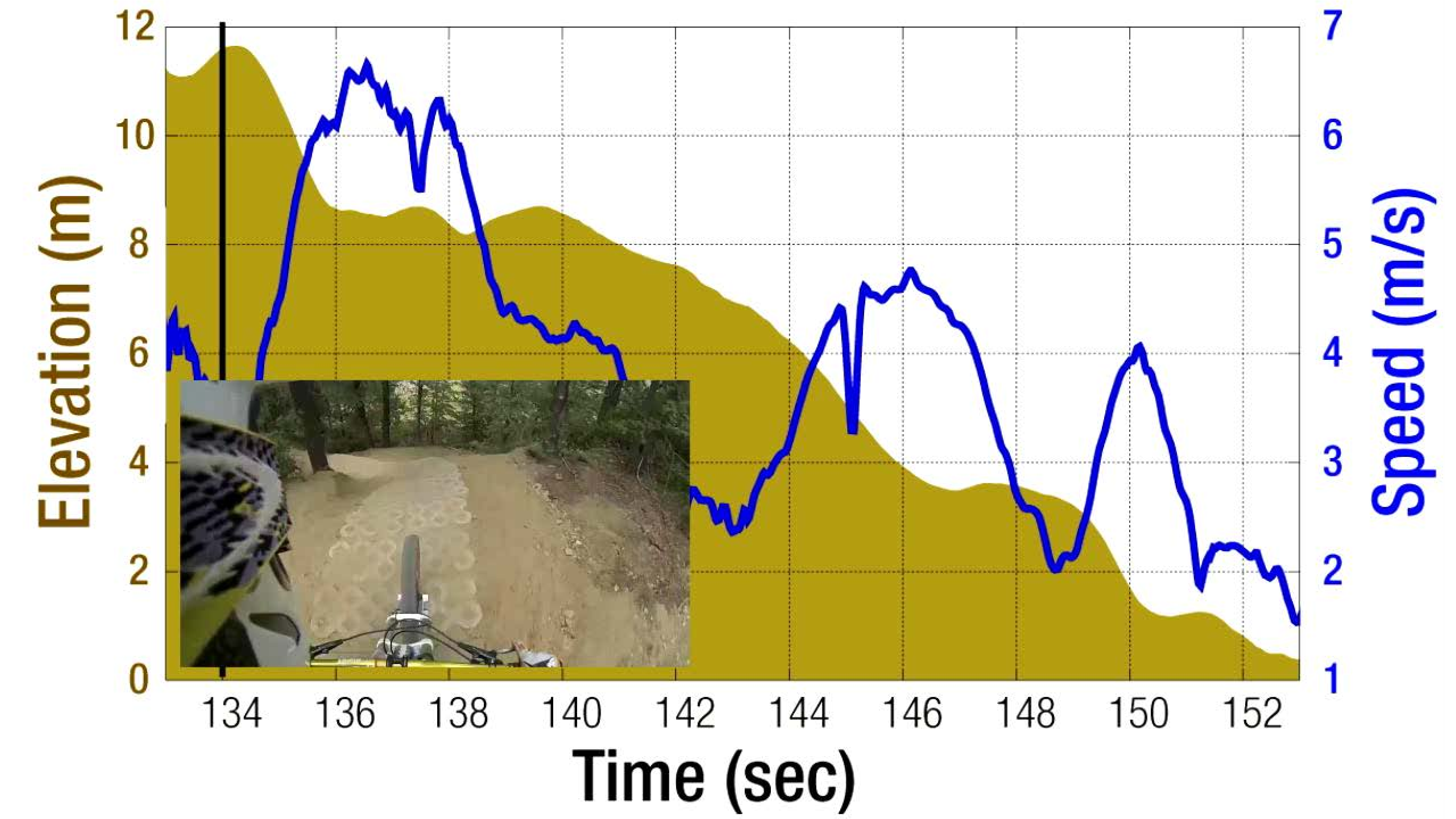
mg

Scale factor:

9.81 m/s²

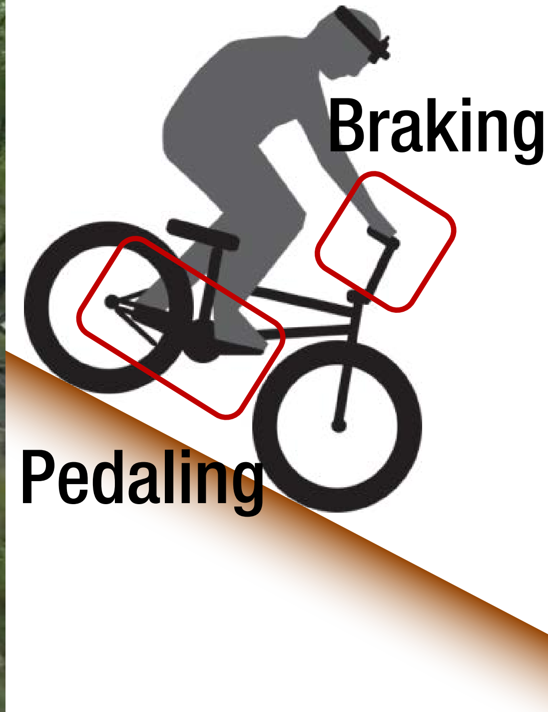
$$\alpha = \frac{g}{a_{ctrpetal}} \tan \theta_b$$

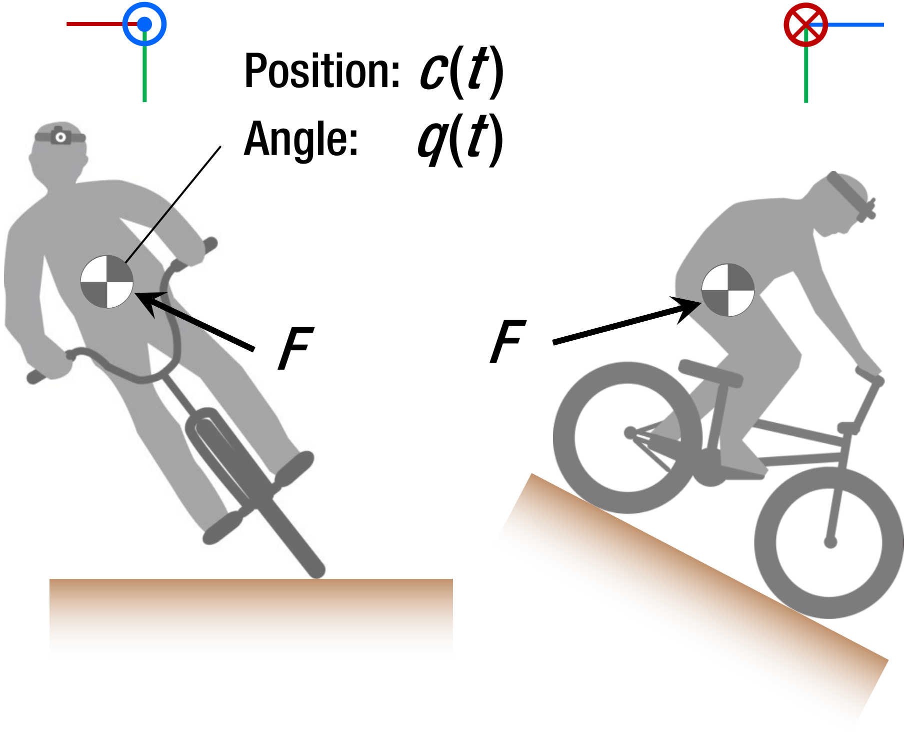
Measured by 3D reconstruction



Elevation (m)
0
2
4
6
8
10
12
Speed (m/s)
1
2
3
4
5
6
7
134
136
138
140
142
144
146
148
150
152
Time (sec)

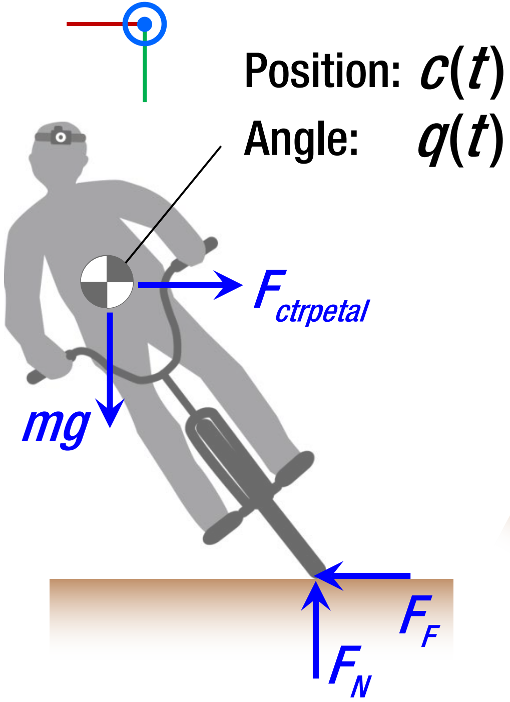

3. Compute Control

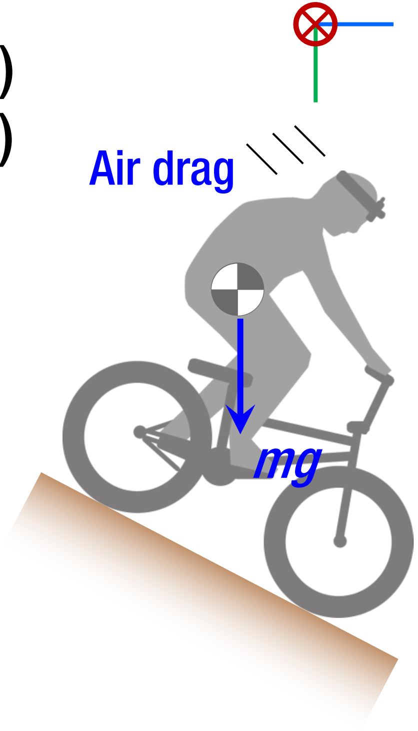

Braking
Pedaling



Linear force:

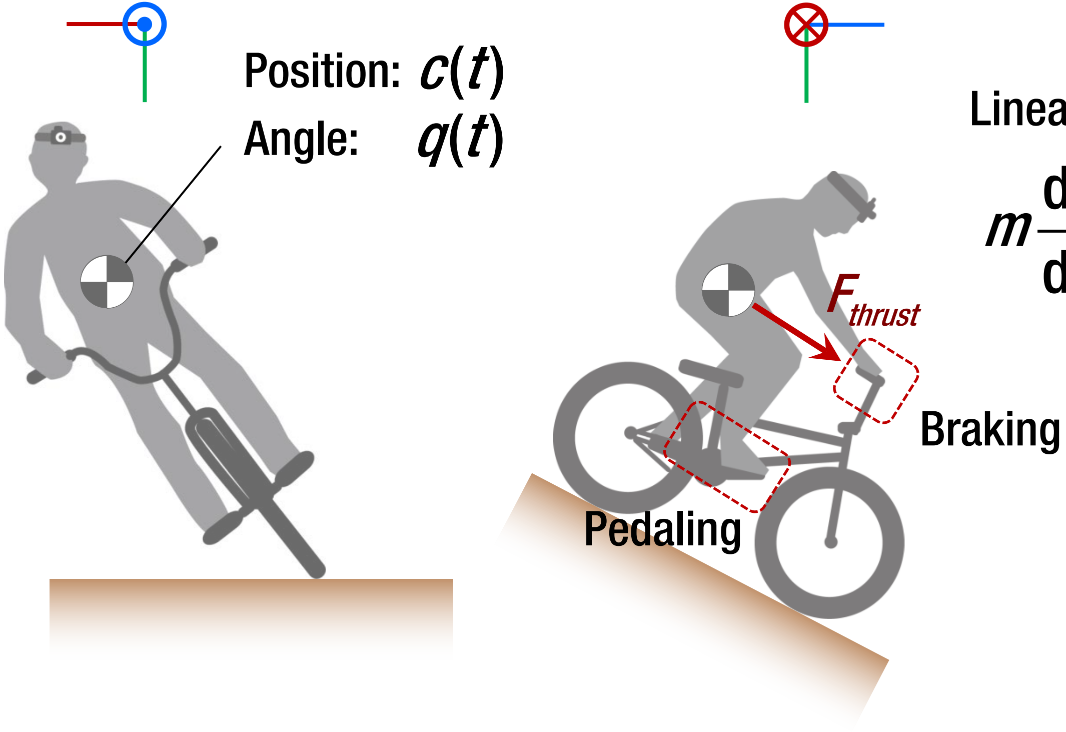
$$m\frac{\mathrm{d}^2c}{\mathrm{d}t^2} = \underline{F}$$





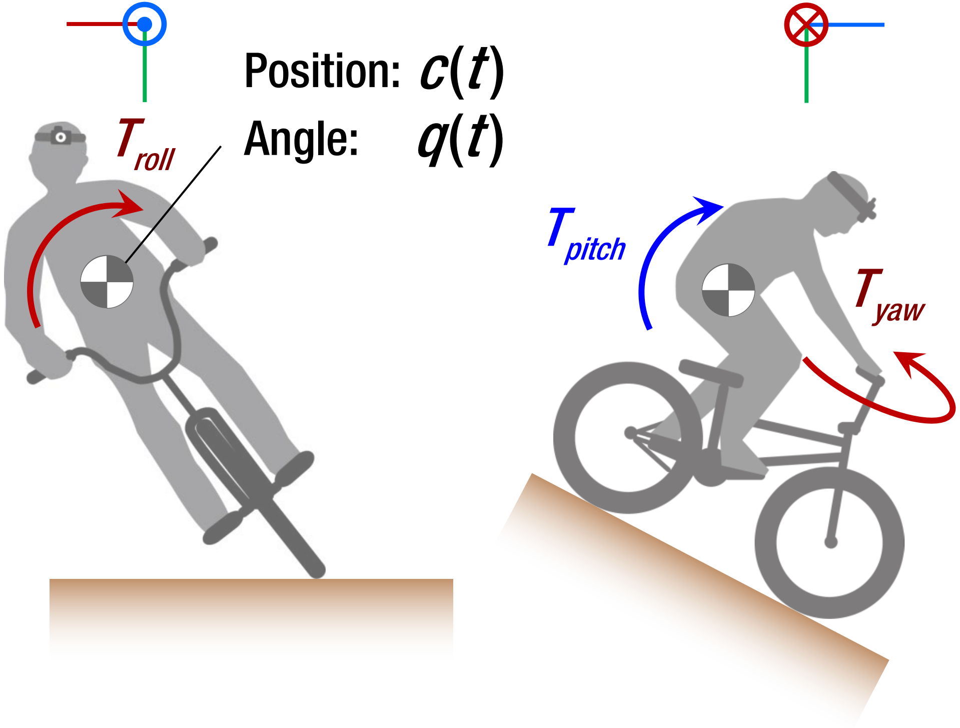
Linear force:

$$m\frac{\mathrm{d}^2 c}{\mathrm{d}t^2} = F = \underline{\sum F_{\text{passive}}} + \sum F_{\text{active}}$$



Linear force:

$$m\frac{\mathrm{d}^2 c}{\mathrm{d}t^2} = F = \sum F_{\text{passive}} + \underline{\sum F_{\text{active}}}$$



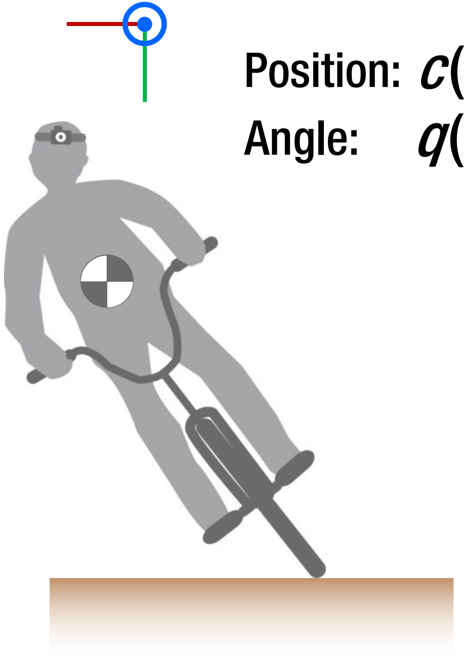
Linear force:

$$m\frac{\mathrm{d}^2 c}{\mathrm{d}t^2} = F = \sum F_{\mathrm{passive}} + \sum F_{\mathrm{active}}$$

Angular force (torque):

$$J\frac{\mathrm{d}^2 q}{\mathrm{d}t^2} + \frac{\mathrm{d}q}{\mathrm{d}t} \times J\frac{\mathrm{d}q}{\mathrm{d}t} = \sum T_{\mathrm{passive}} + \sum T_{\mathrm{active}}$$

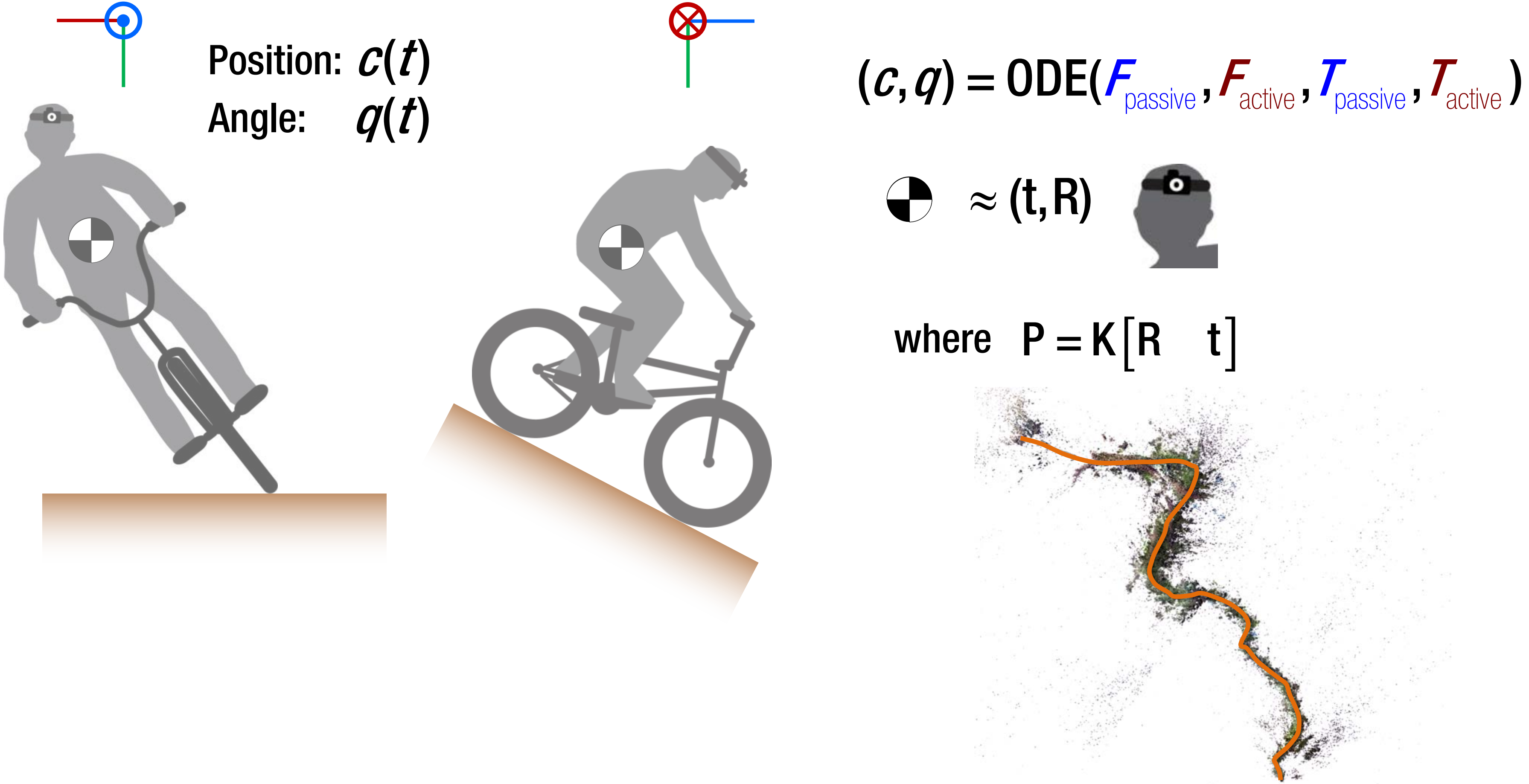
J : Moment of inertia

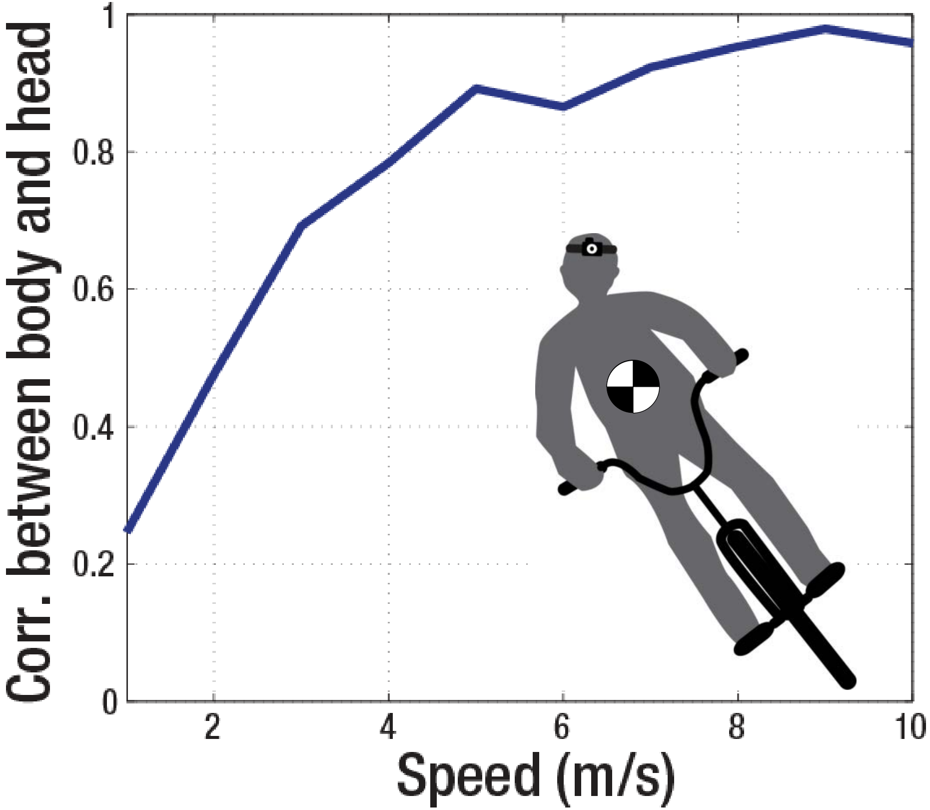


Position: $c(t)$

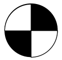
Angle: $q(t)$

$$(c, q) = \mathrm{ODE}(F_{\text{passive}}, F_{\text{active}}, T_{\text{passive}}, T_{\text{active}})$$

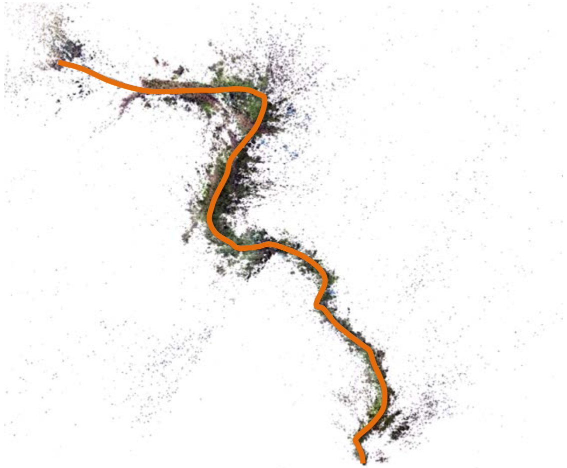

Position: c(t)
Angle: q(t)
(c,q) = ODE(F_passive, F_active, T_passive, T_active)
≈ (t,R)
where P = K[R t]



$$(c, q) = \mathrm{ODE}(F_{passive}, F_{active}, T_{passive}, T_{active})$$

 $\approx (t, R)$ 

where $P = K\begin{bmatrix} R & t \end{bmatrix}$

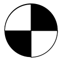


Inverse control:

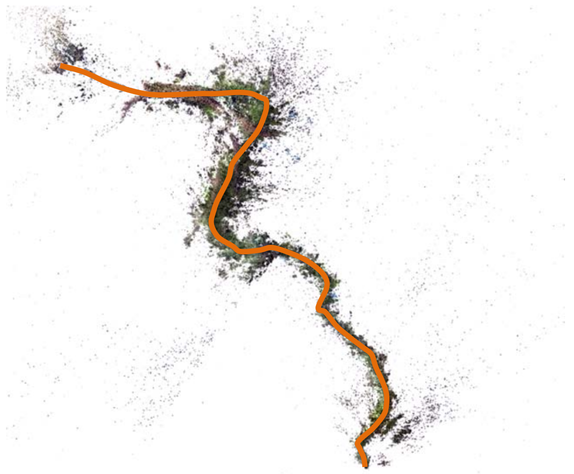
$$\underset{F,T,X}{\text{minimize}}\ \underbrace{E_{\text{SfM}}}_{\text{Reprojection error}}$$

$$\text{subject to}\quad (\mathrm{t},\mathrm{R}) = \mathrm{ODE}(F,T)$$

$$(c,q) = \mathrm{ODE}(F_{\text{passive}}, F_{\text{active}}, T_{\text{passive}}, T_{\text{active}})$$

 $\approx (\mathrm{t},\mathrm{R})$ 

where $\mathrm{P} = \mathrm{K}\begin{bmatrix}\mathrm{R} & \mathrm{t}\end{bmatrix}$



Inverse control:

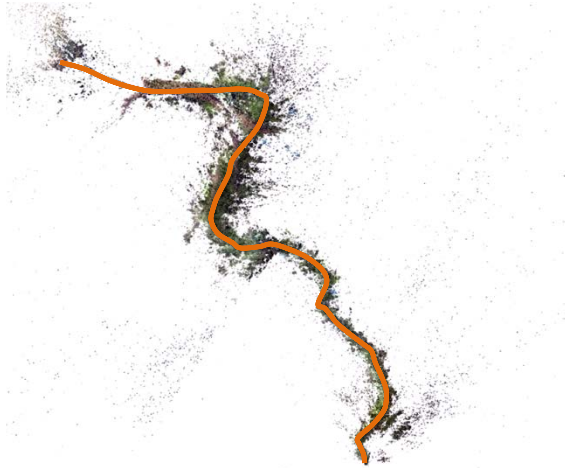
$$\underset{F,T,X}{\text{minimize}}\; E_{\text{SfM}} + \lambda \underbrace{E_{\text{reg}}(F,T)}_{\text{Temporal regularization}}$$

$$\text{subject to}\quad (\mathrm{t},\mathrm{R}) = \mathrm{ODE}(F,T)$$

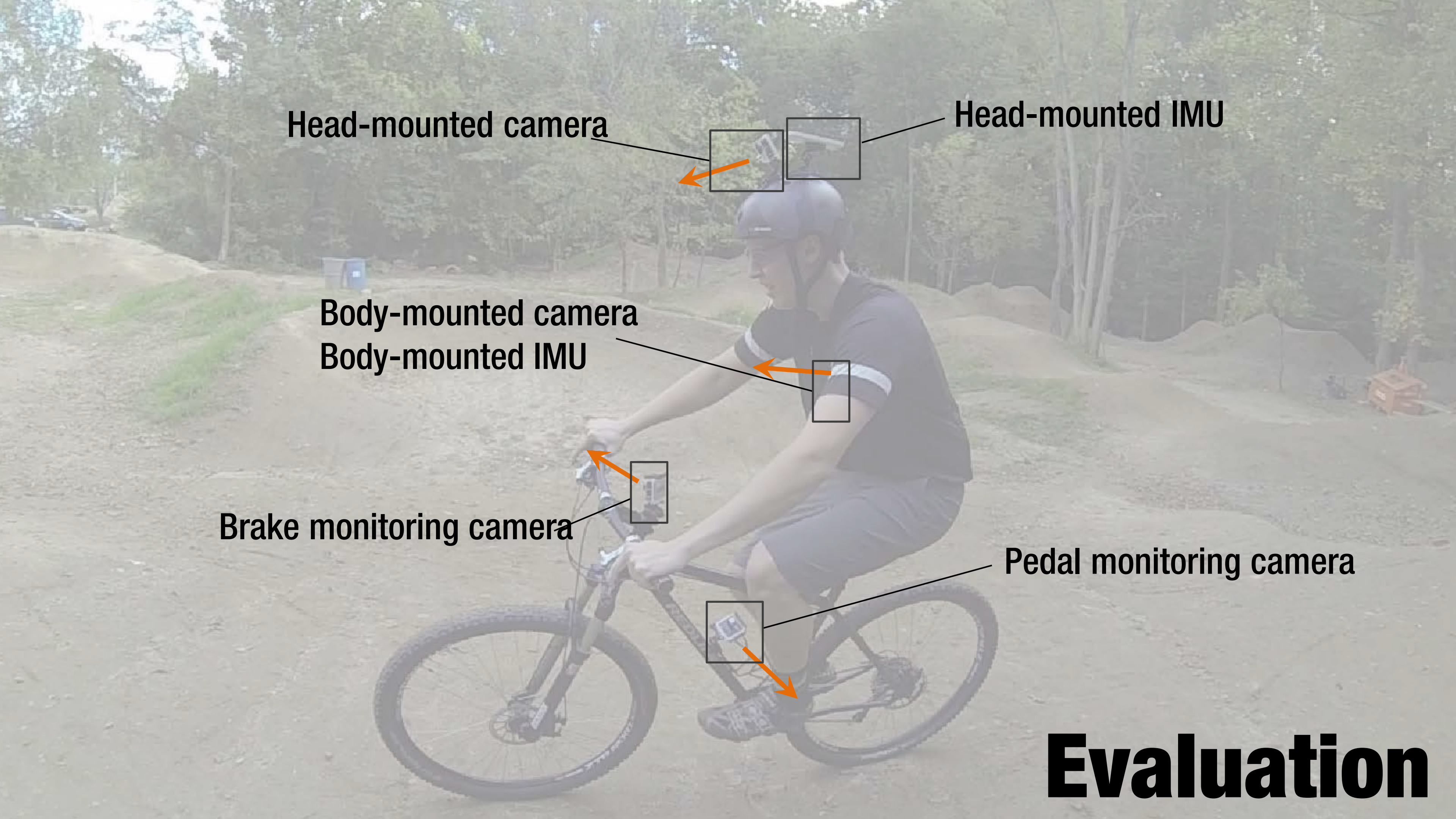
$$(c,q) = \mathrm{ODE}(F_{\text{passive}}, F_{\text{active}}, T_{\text{passive}}, T_{\text{active}})$$

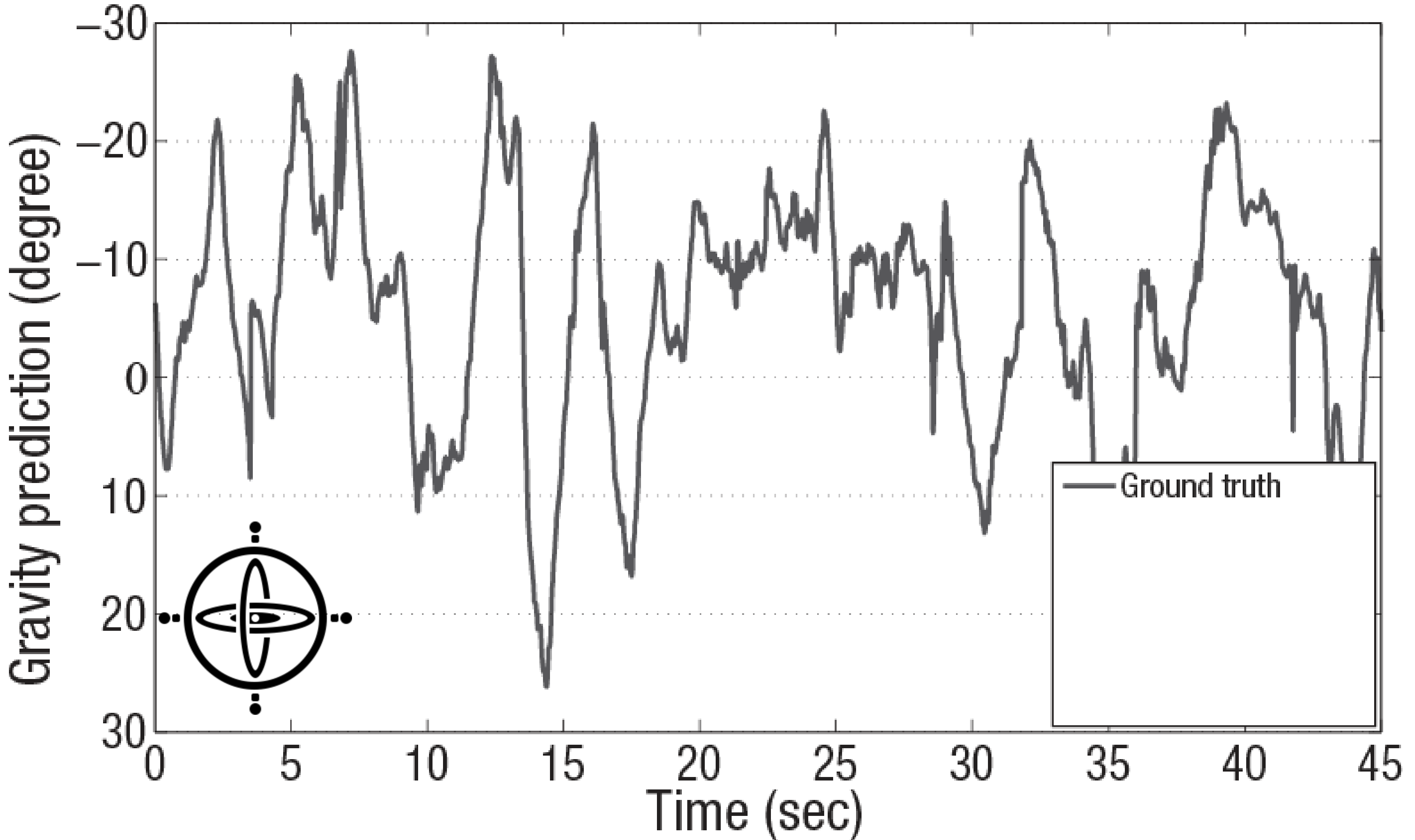
$$\oplus \approx (\mathrm{t},\mathrm{R})$$

$$\text{where}\quad \mathrm{P} = \mathrm{K}\begin{bmatrix}\mathrm{R} & \mathrm{t}\end{bmatrix}$$

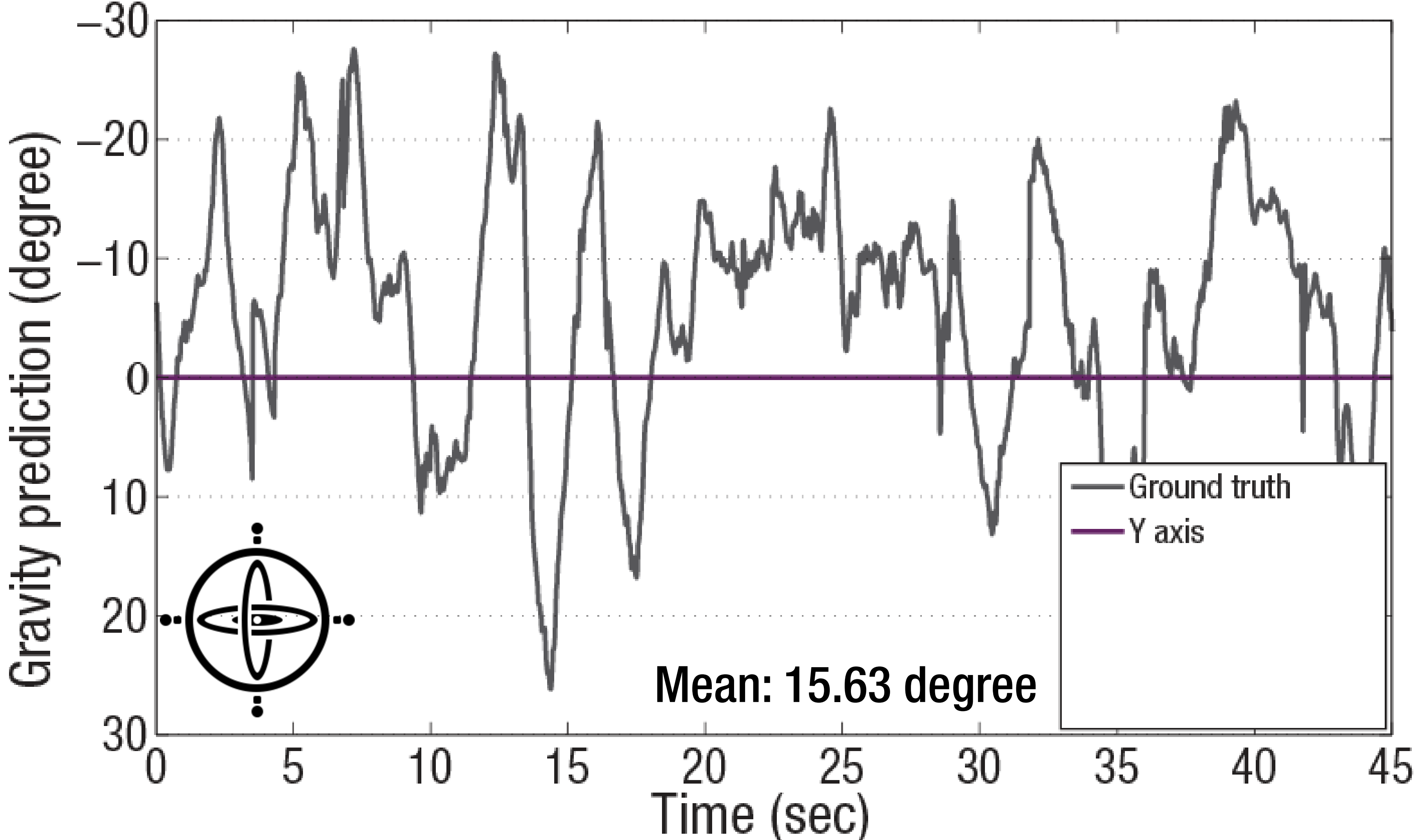


Evaluation

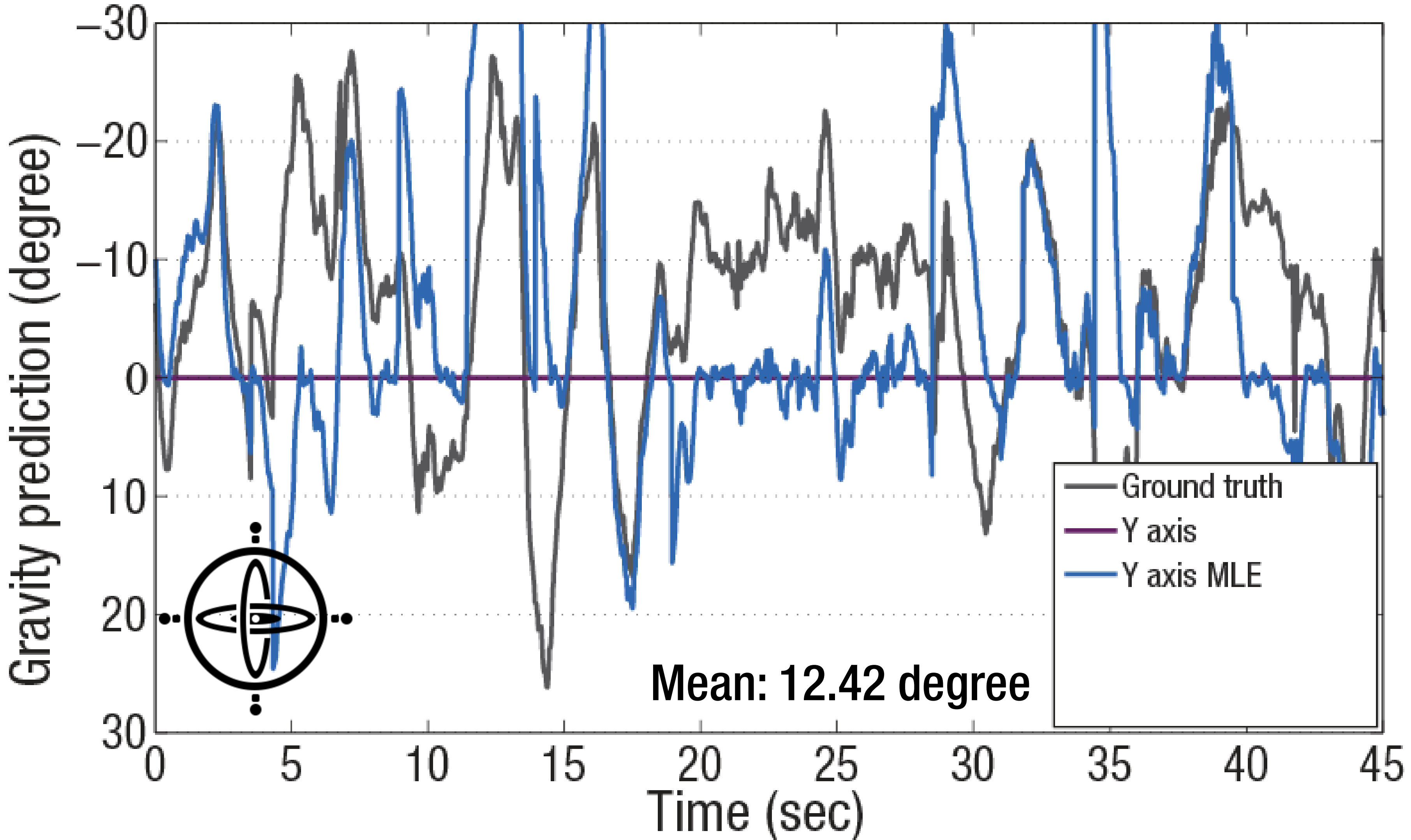

Head-mounted camera
Head-mounted IMU
Body-mounted camera
Body-mounted IMU
Brake monitoring camera
Pedal monitoring camera

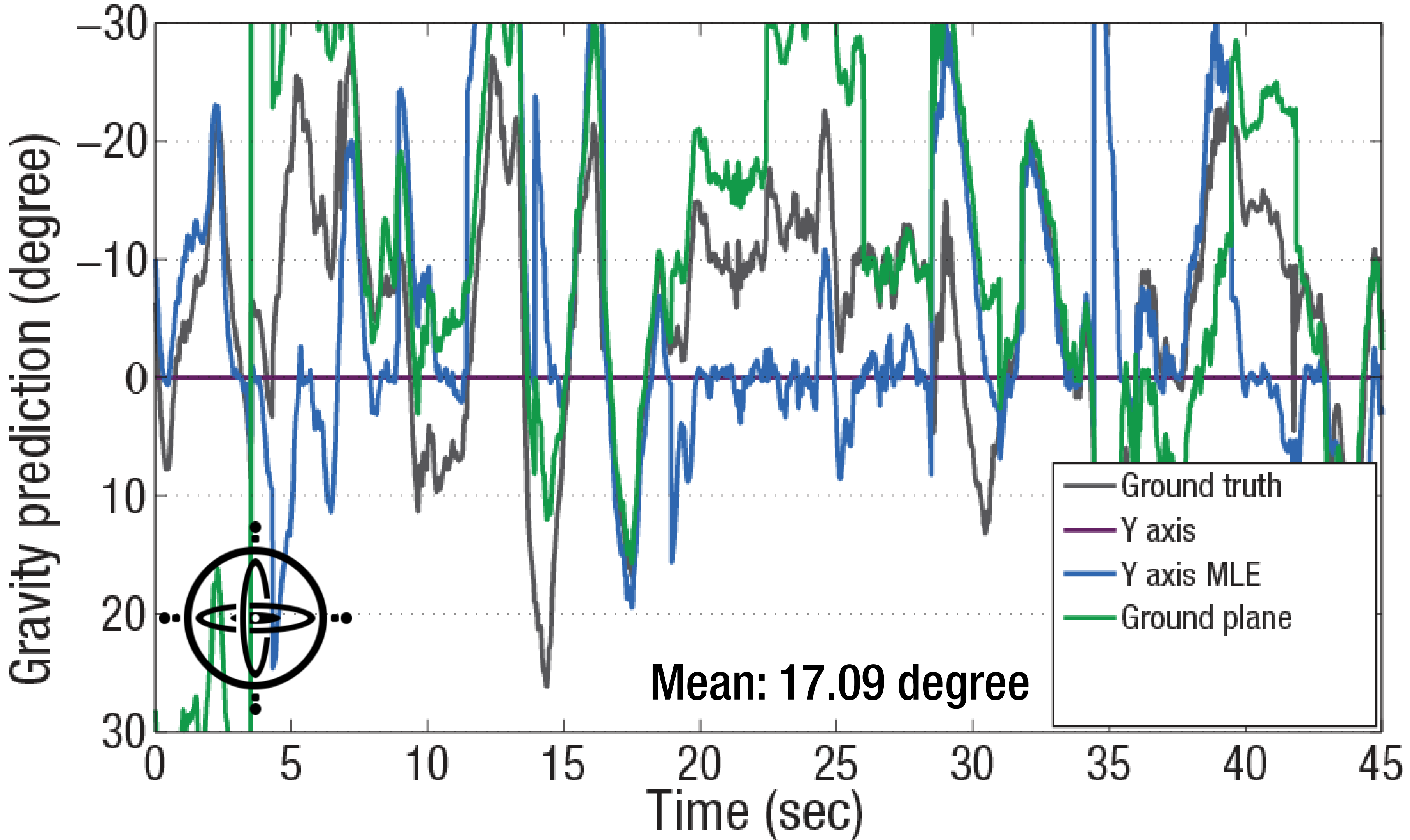


Gravity prediction (degree)
−30
−20
−10
0
10
20
30
0
5
10
15
20
25
30
35
40
45
Time (sec)
Ground truth

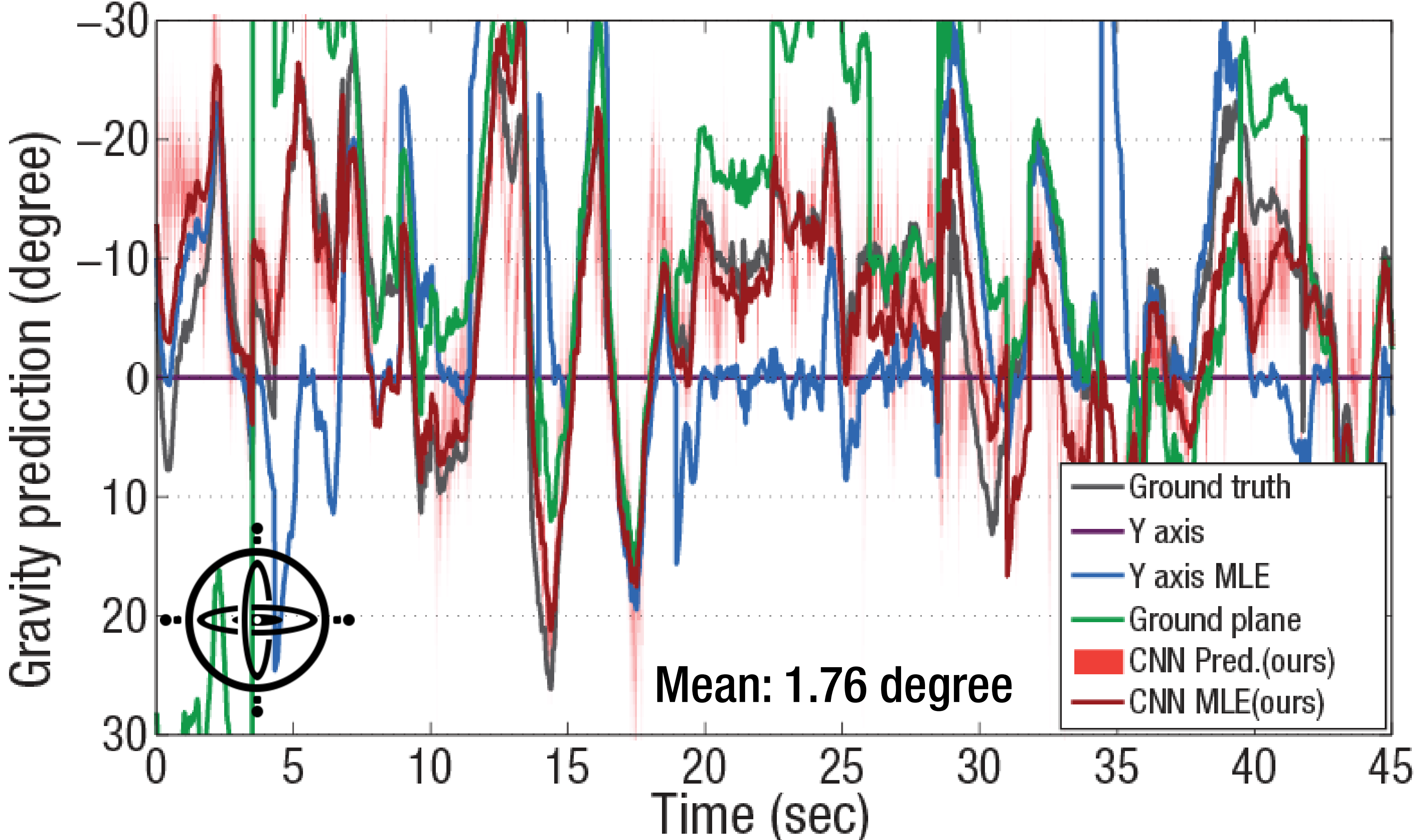


Gravity prediction (degree)
−30
−20
−10
0
10
20
30
Time (sec)
0
5
10
15
20
25
30
35
40
45
Ground truth
Y axis
Mean: 15.63 degree

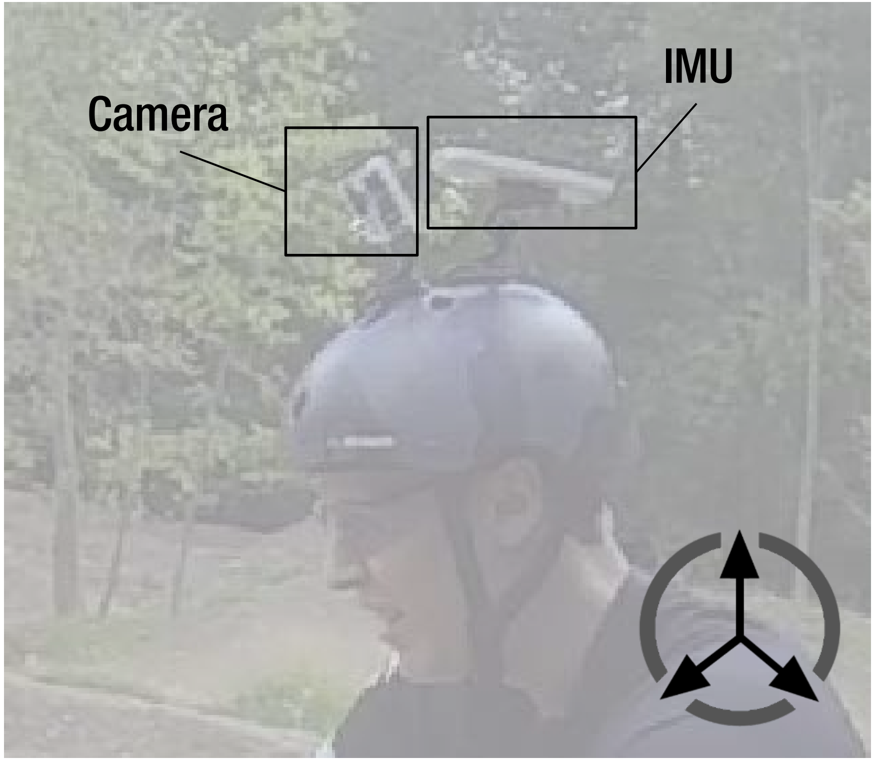

Gravity prediction (degree)
−30
−20
−10
0
10
20
30
0
5
10
15
20
25
30
35
40
45
Time (sec)
Ground truth
Y axis
Y axis MLE
Mean: 12.42 degree

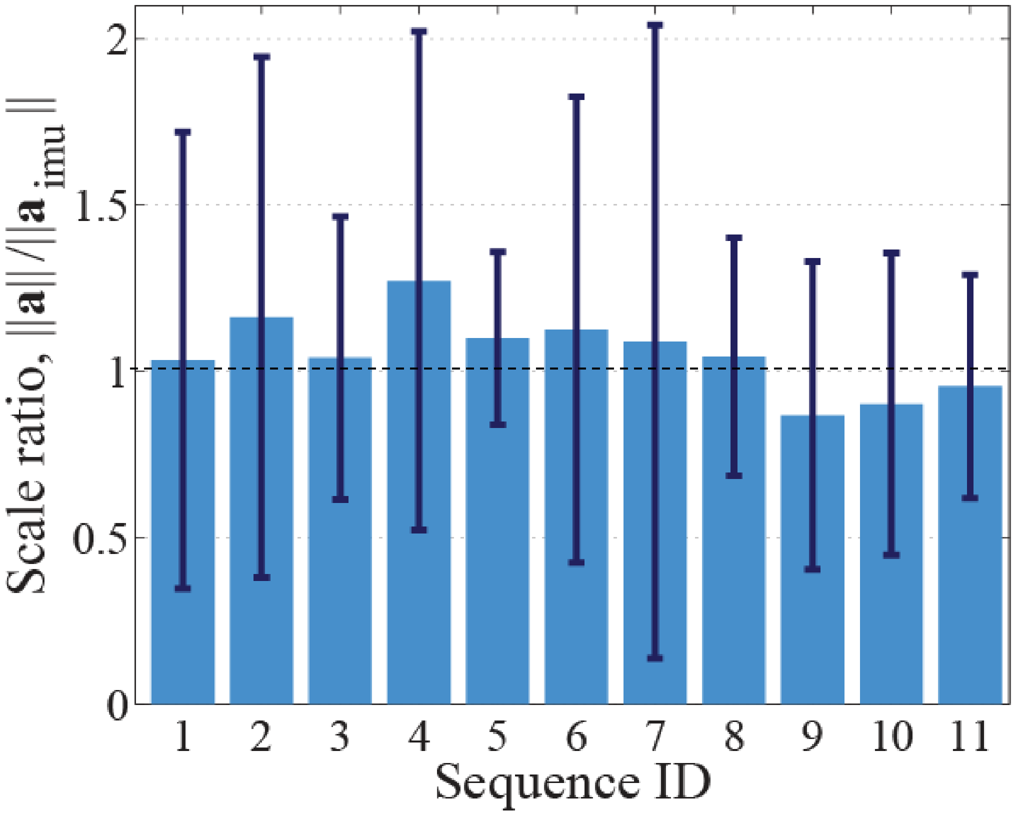


Gravity prediction (degree)
−30
−20
−10
0
10
20
30
0
5
10
15
20
25
30
35
40
45
Time (sec)
Ground truth
Y axis
Y axis MLE
Ground plane
Mean: 17.09 degree

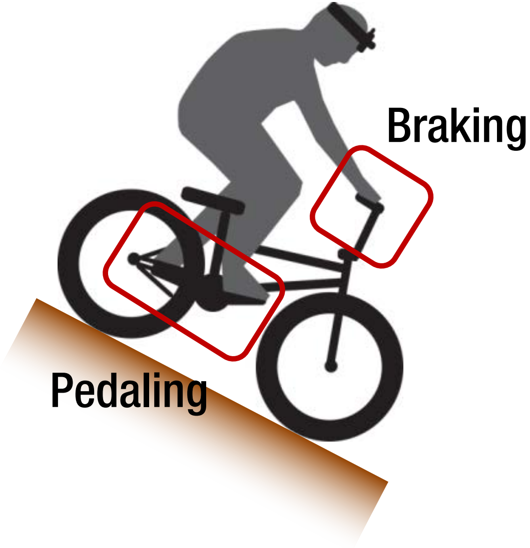


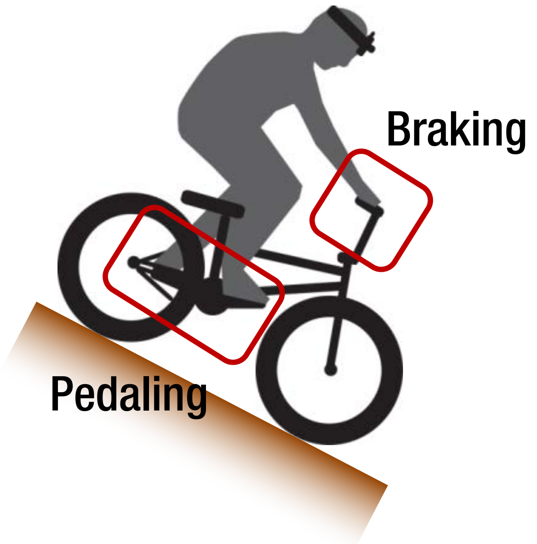
Gravity prediction (degree)
−30
−20
−10
0
10
20
30
0
5
10
15
20
25
30
35
40
45
Time (sec)
Mean: 1.76 degree
Ground truth
Y axis
Y axis MLE
Ground plane
CNN Pred.(ours)
CNN MLE(ours)


IMU
Camera

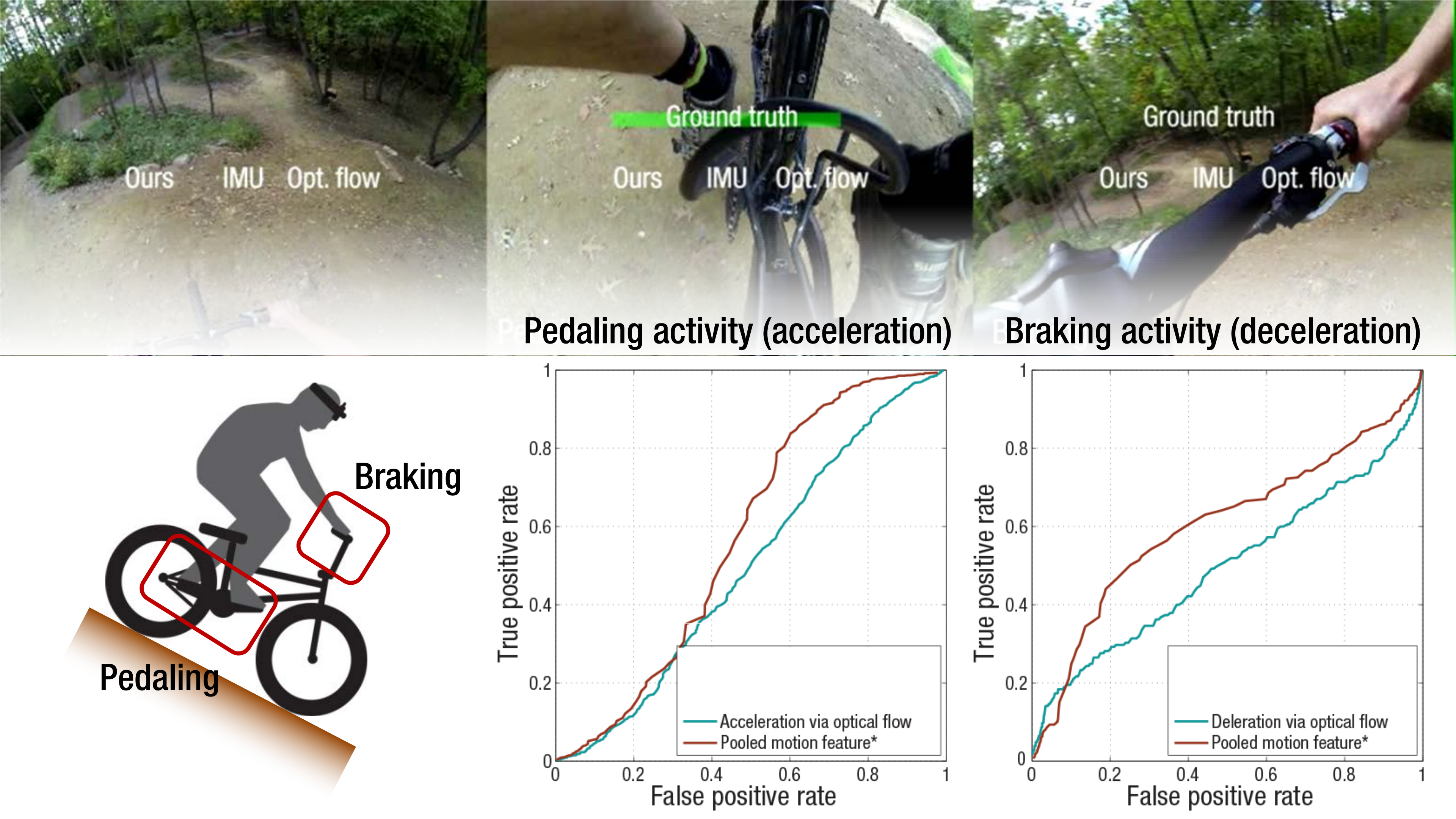

Scale ratio, ||a||/||a imu||
Sequence ID
0
0.5
1
1.5
2
1 2 3 4 5 6 7 8 9 10 11

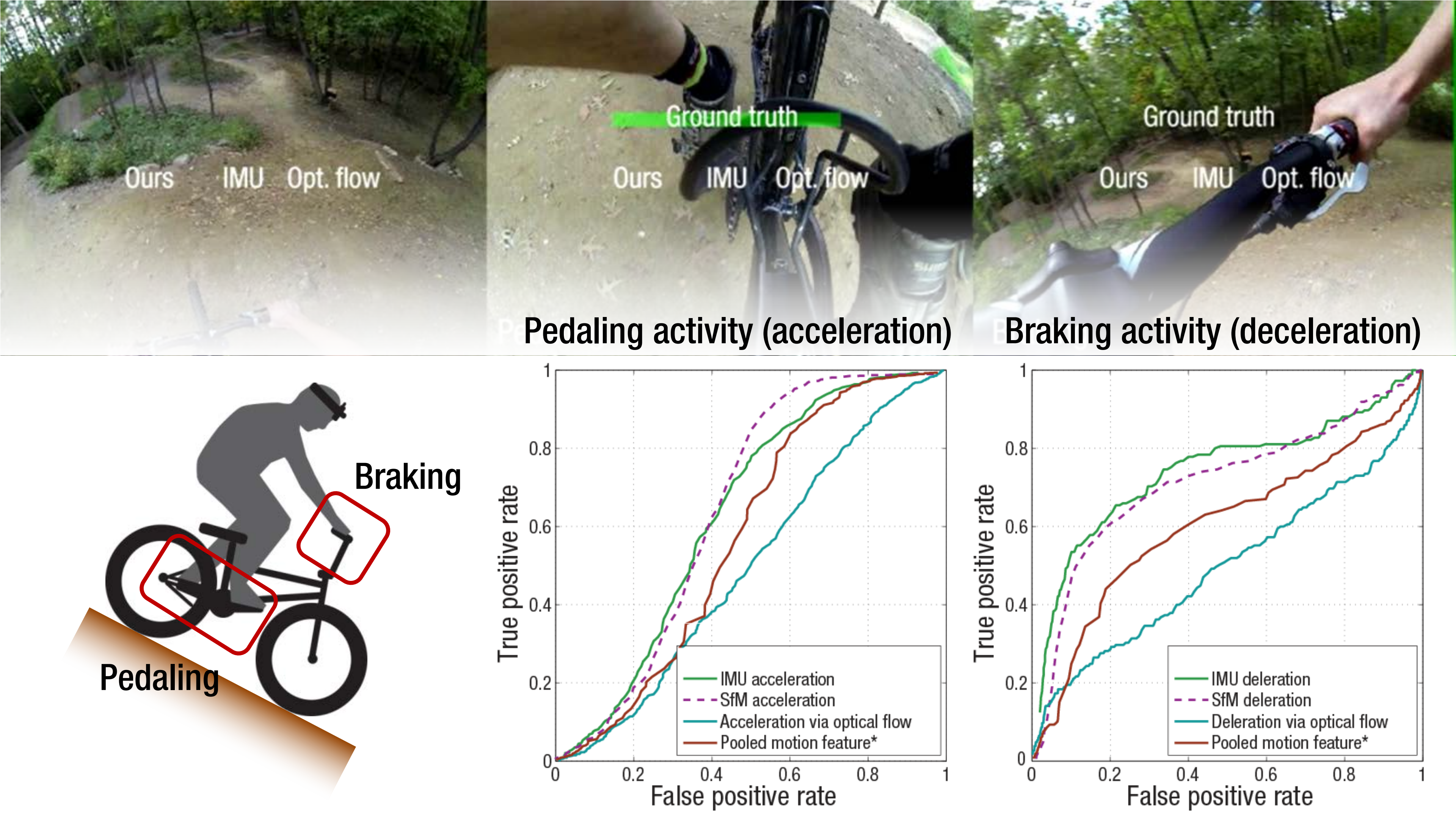

Ours
IMU
Opt. flow
Ground truth
Ours
IMU
Opt. flow
Pedaling activity (acceleration)
Ground truth
Ours
IMU
Opt. flow
Braking activity (deceleration)


Braking
Pedaling

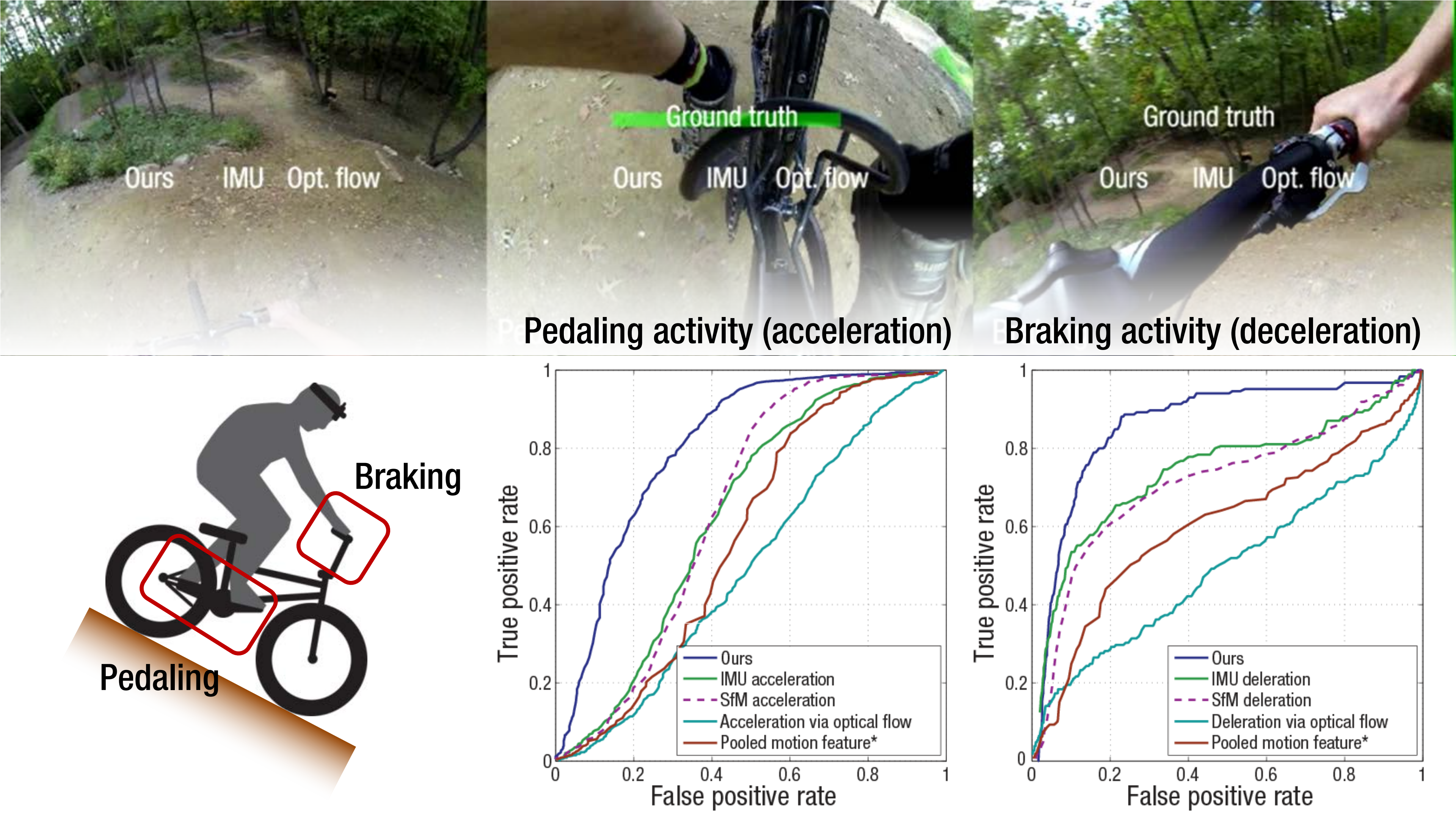


$$m\frac{d^2 c}{d t^2} = F = \sum F_{passive} + \underline{\sum F_{active}}$$

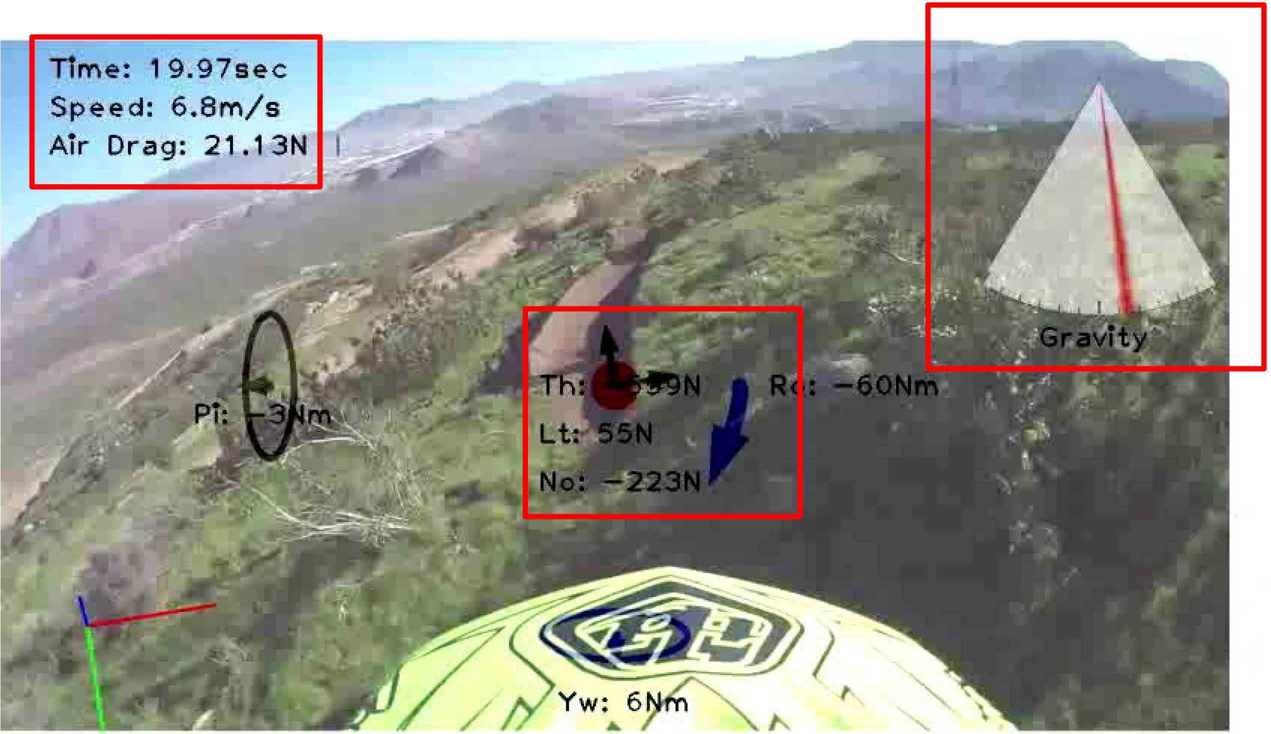

Ours
IMU
Opt. flow
Ground truth
Ours
IMU
Opt. flow
Ground truth
Ours
IMU
Opt. flow
Pedaling activity (acceleration)
Braking activity (deceleration)
Braking
Pedaling
True positive rate
False positive rate
0
0.2
0.4
0.6
0.8
1
Acceleration via optical flow
Pooled motion feature*
True positive rate
False positive rate
0
0.2
0.4
0.6
0.8
1
Deleration via optical flow
Pooled motion feature*

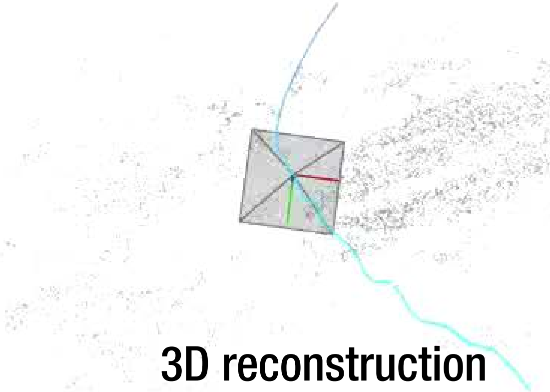


Ours
IMU
Opt. flow
Ground truth
Ours
IMU
Opt. flow
Ground truth
Ours
IMU
Opt. flow
Pedaling activity (acceleration)
Braking activity (deceleration)
Braking
Pedaling
True positive rate
False positive rate
IMU acceleration
SfM acceleration
Acceleration via optical flow
Pooled motion feature*
True positive rate
False positive rate
IMU deleration
SfM deleration
Deleration via optical flow
Pooled motion feature*
0
0.2
0.4
0.6
0.8
1



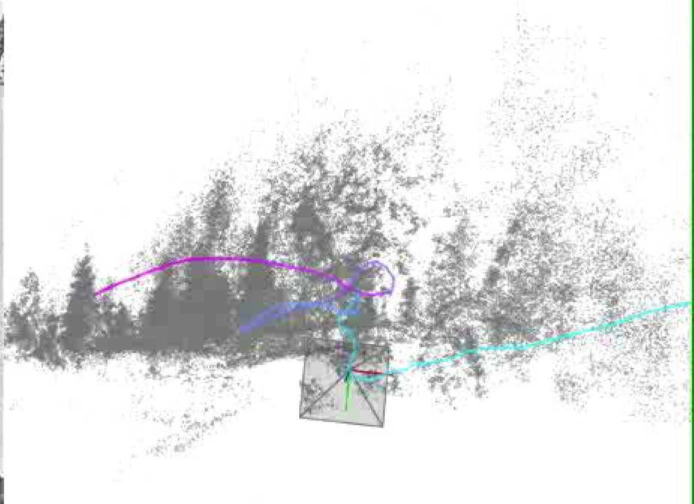
Ours
IMU
Opt. flow
Ground truth
Ours
IMU
Opt. flow
Ground truth
Ours
IMU
Opt. flow
Pedaling activity (acceleration)
Braking activity (deceleration)
Braking
Pedaling
True positive rate
False positive rate
0
0.2
0.4
0.6
0.8
1
Ours
IMU acceleration
SfM acceleration
Acceleration via optical flow
Pooled motion feature*
True positive rate
False positive rate
0
0.2
0.4
0.6
0.8
1
Ours
IMU deleration
SfM deleration
Deleration via optical flow
Pooled motion feature*





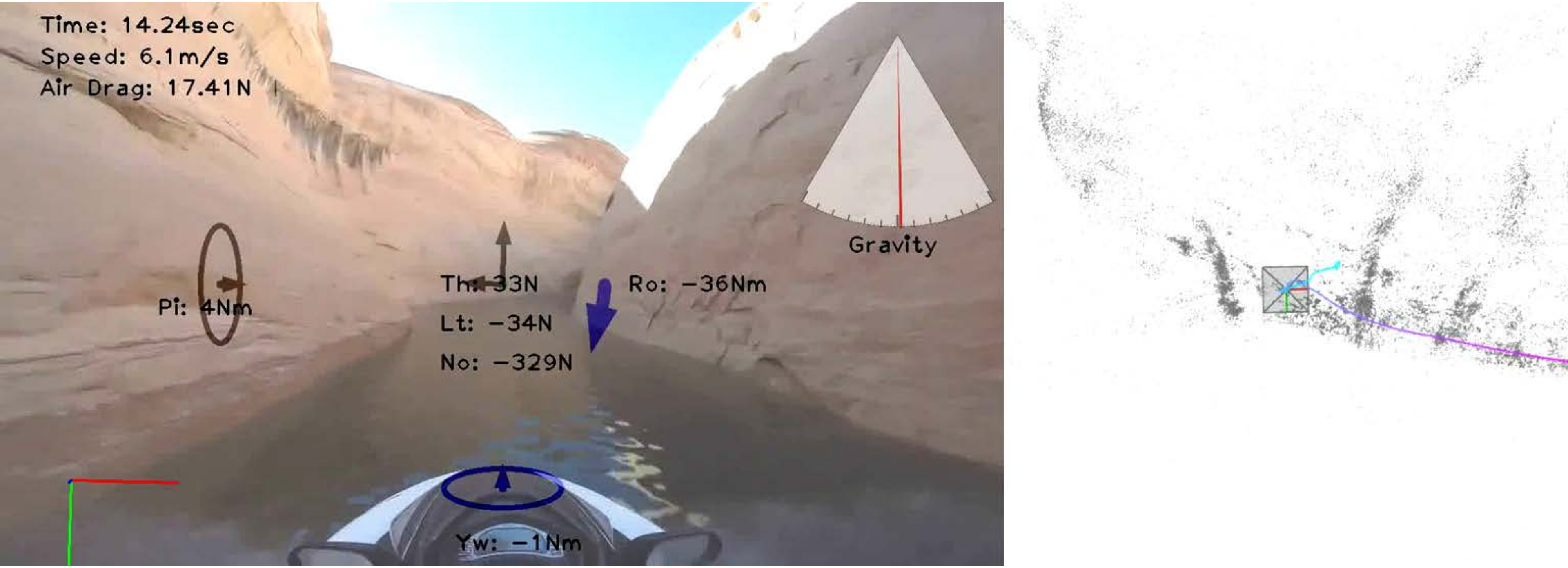
3D reconstruction

https://www.youtube.com/watch?v=aVJ45wlUE88



3D reconstruction

https://www.youtube.com/watch?v=pCcuKClUpLs


Time: 14.24sec
Speed: 6.1m/s
Air Drag: 17.41N
Gravity
Th: 33N
Lt: -34N
No: -329N
Ro: -36Nm
Pi: 4Nm
Yw: -1Nm

3D reconstruction

https://www.youtube.com/watch?v=rnvvsjstveM


First person vision


Third person vision

Force from Motion:

Decoding Physical Sensation from a First Person Video

http://www.seas.upenn.edu/~hypar/ffm.html