

Autonomous Vehicle Control at the Limits

Krisada (Mick) Kritayakirana



The Future of Automobile
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Pikes Peak project



- Drive 12.4 miles autonomously
- Test robustness
 - Paved and gravel roads
 - Weather changes all the time
- Not much room for error



Motivation

- **Build a controller that can mimic a racecar driver**
- **End goal: driver assistance system**



Controller objectives



Mindset

- Design a *simple* (yet *robust*) driver assistance system that can assist even the best driver

Objectives

- Track a path
- Stability
- Utilize tire force



Controller Structure



Understanding the environment (sensing)

1. Path description
2. Friction estimation

Controlling

3. Steering controller – path tracking & stability
 - 3.1 Feedforward controller
 - 3.2 Feedback controller
4. Longitudinal controller – utilize tire force
 - 4.1 Feedforward controller
 - 4.2 Feedback controller – tire slip circle

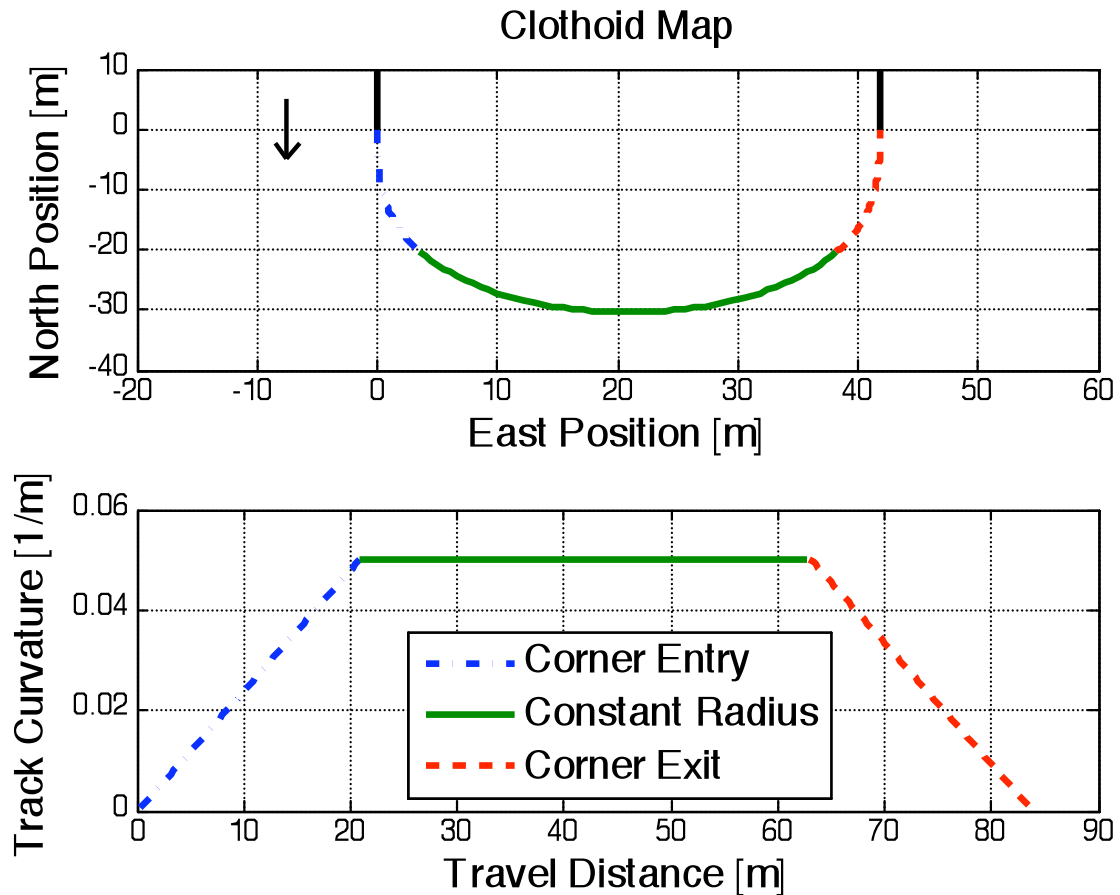
Predetermined path



- **Clothoid curve:**
has a linear
curvature

$$\frac{1}{R} \propto s$$

- **Simplify structure**
- **Very few parameters**



Estimated friction



- **Need for feedforward controller (driver modeling)**
 - **Governs acceleration**
 - Speed profile (corner entry speed, braking point, etc.)
- **Controller should be robust to any friction *variation***

Controller Structure



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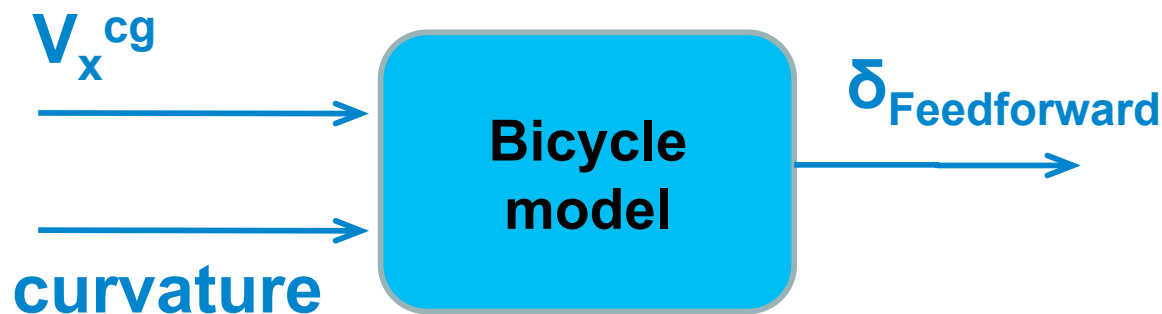
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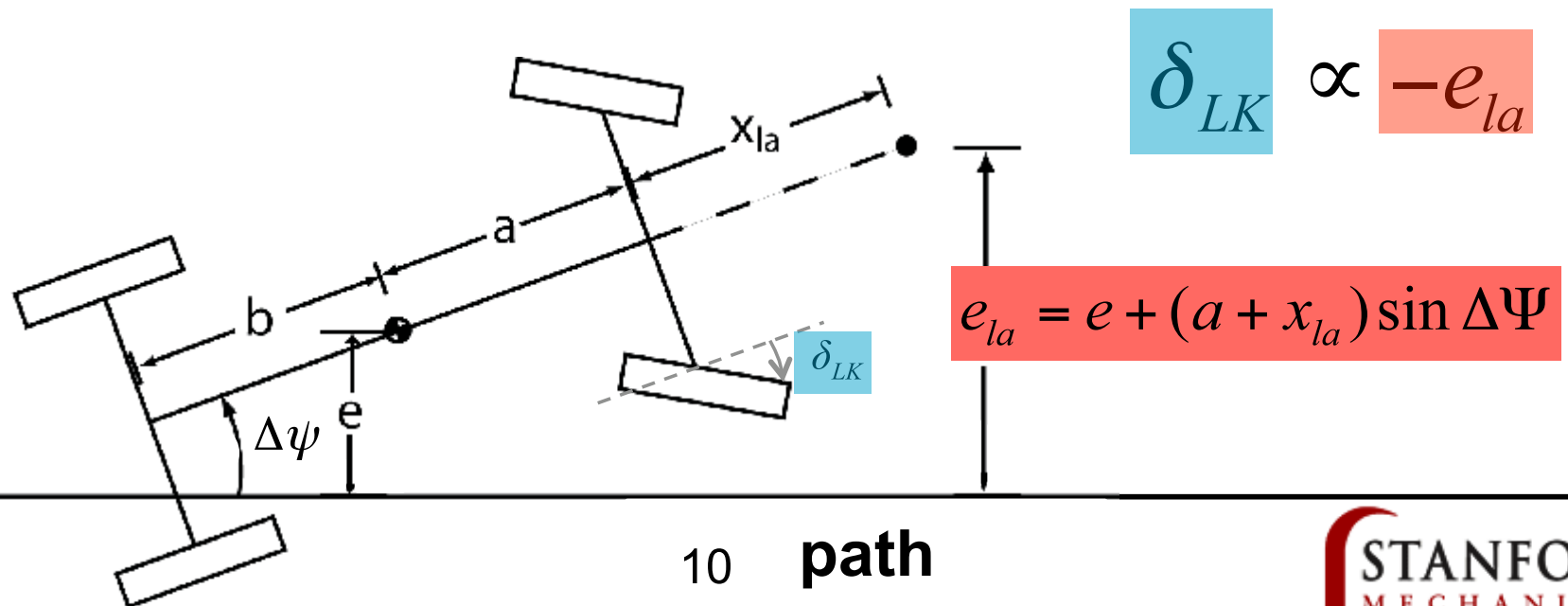
Feedforward steering controller

- Provides *path tracking*
- Uses a linear bicycle model
- Any modeling error → steering feedback



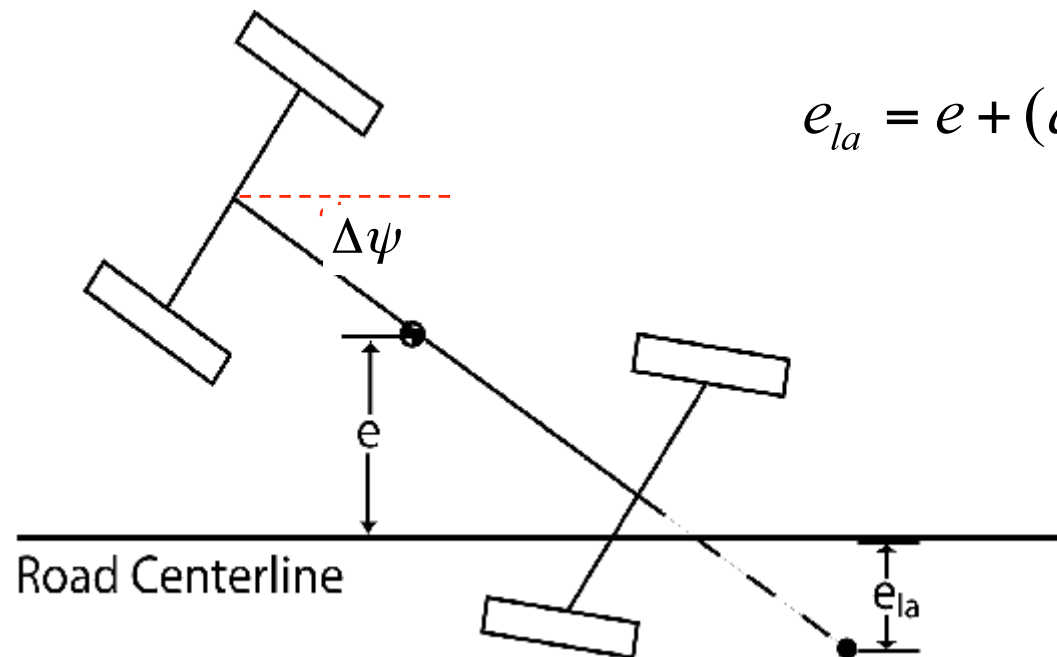
Feedback steering controller

- Provides *tracking*
- Feedback steering - lanekeeping system (Rossetter 2003)
 - based on lookahead error ($-e_{la}$)



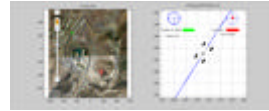
Feedback steering controller

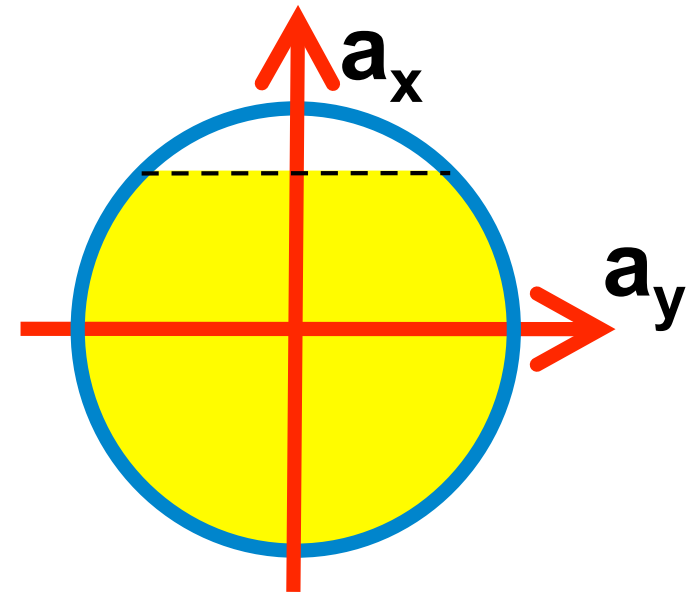
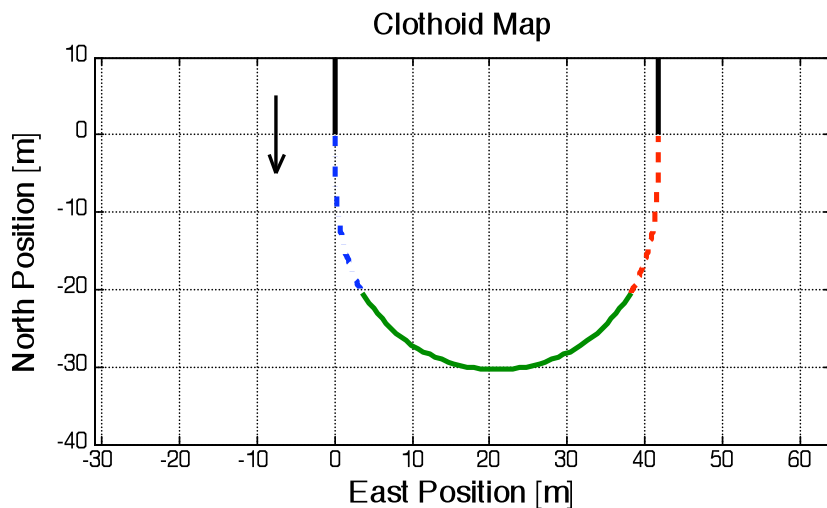
- Lanekeeping system provides *stability* (Hindiye et al, 2008)
- Provides countersteer



$$e_{la} = e + (a + x_{la}) \sin \Delta\Psi$$

Feedforward longitudinal controller

- Utilizes tire force on a “g-g” diagram
- Mimicking a racecar driver using trail-braking and throttle on exit 
- Find $a_x(s)$ along the path



Tire slip circle feedback

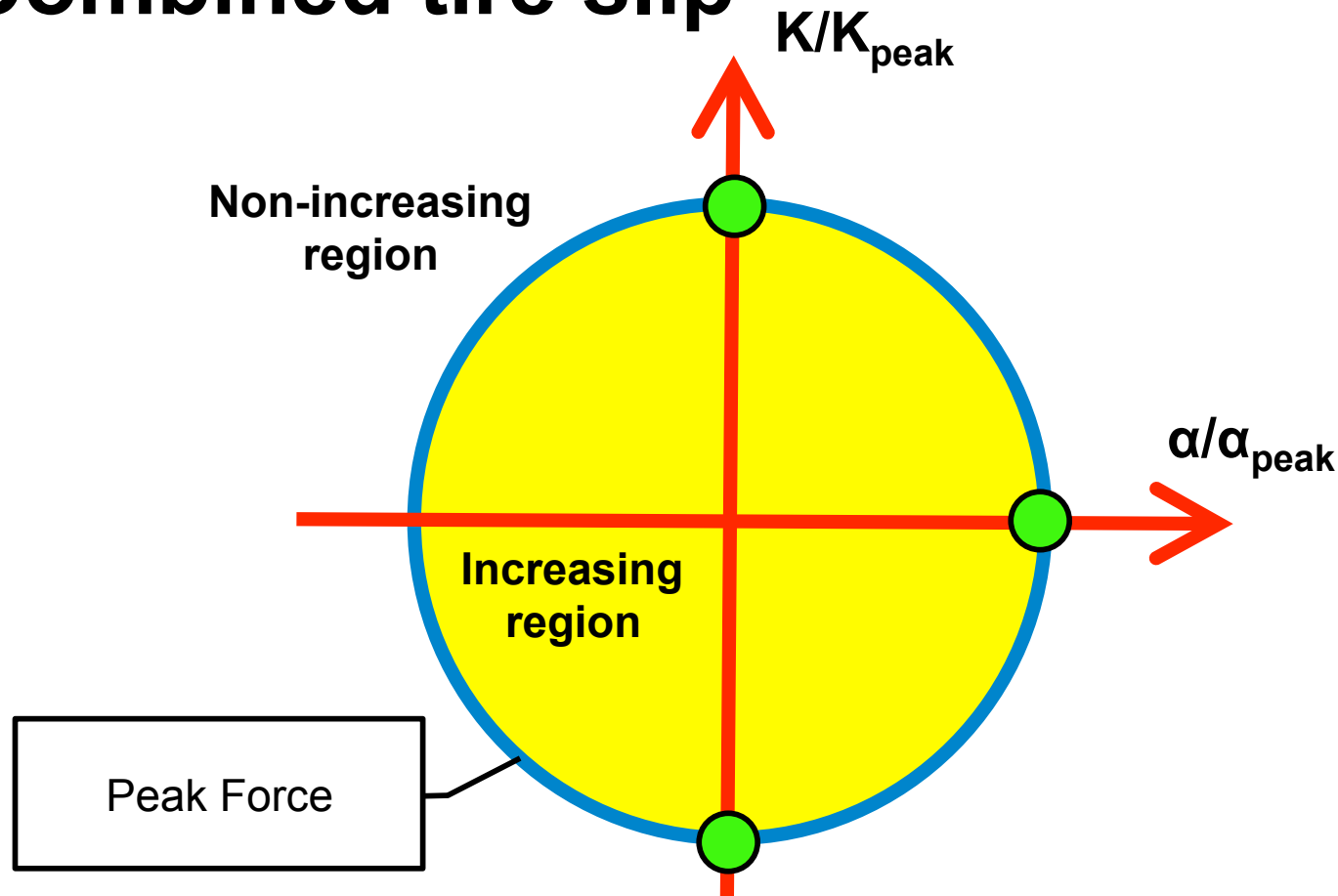


- **Utilizing tire force even when the surface has high friction variation**
 - Prevent excessive front or rear slip
 - Ensure that the tires are operating at their limits
- **Monitor and control *front* and *rear* tire slip**

Tire slip circle feedback



- Combined tire slip



Audi TTS Pikes Peak



- **Modified by-wire Audi TTS**
 - Electronic power steering
 - Active brake booster
 - Throttle by-wire
- **DGPS**
- **Test on a dirt surface**



At the limits

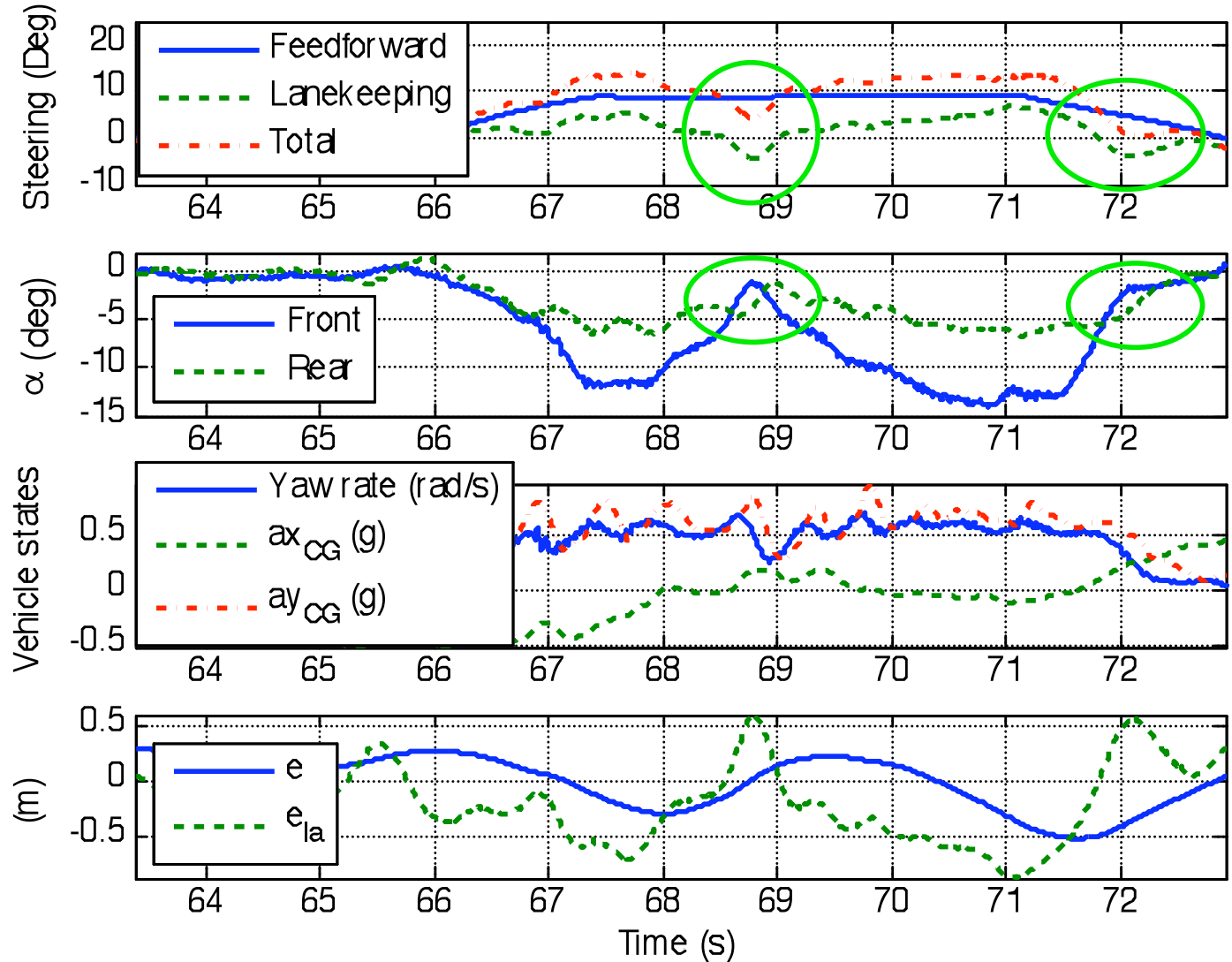


Controller behavior



Steering

- Provides counter steer
- Lateral error (e) within 0.5 m

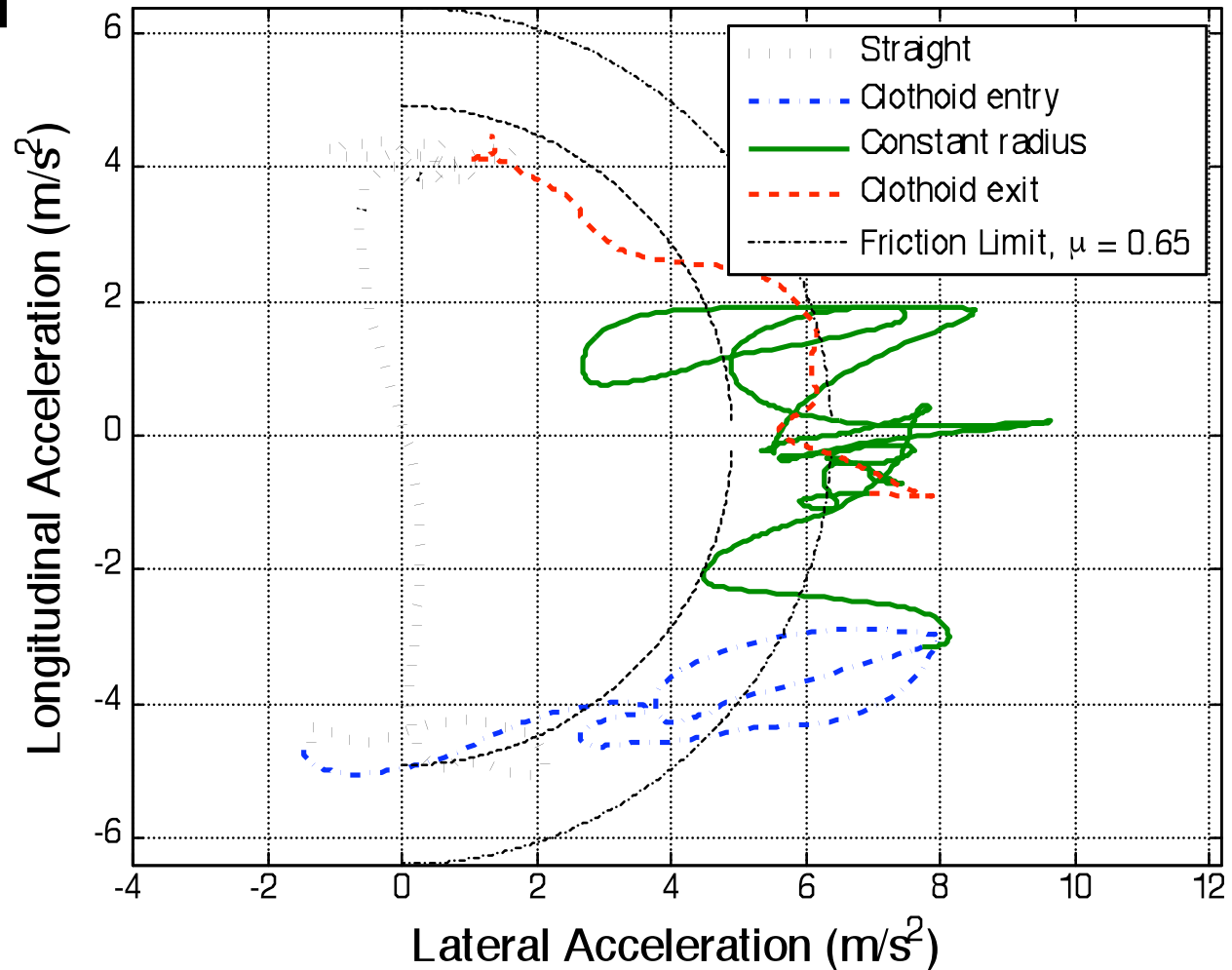


Controller behavior



- **Underestimated friction, controller still pushes the vehicle to the limits**

g-g Diagram, with slip circle feedback



Conclusion

- With a *simple* structure, controller can drive a vehicle autonomously at the *limits*, on a rough dirt surface, while *tracking* a path
- Can be adapted to a driver assistance system



Next...

- **Assistance System for**
 - Human - human interface?
 - Robot
- **When can Shelley beat a racecar driver?**

