DLR

Bicycle & Motorcycle Dynamics 2023

Experiences with Training and Study Design Mechanisms Utilizing the DLR Bike Simulator

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Introduction

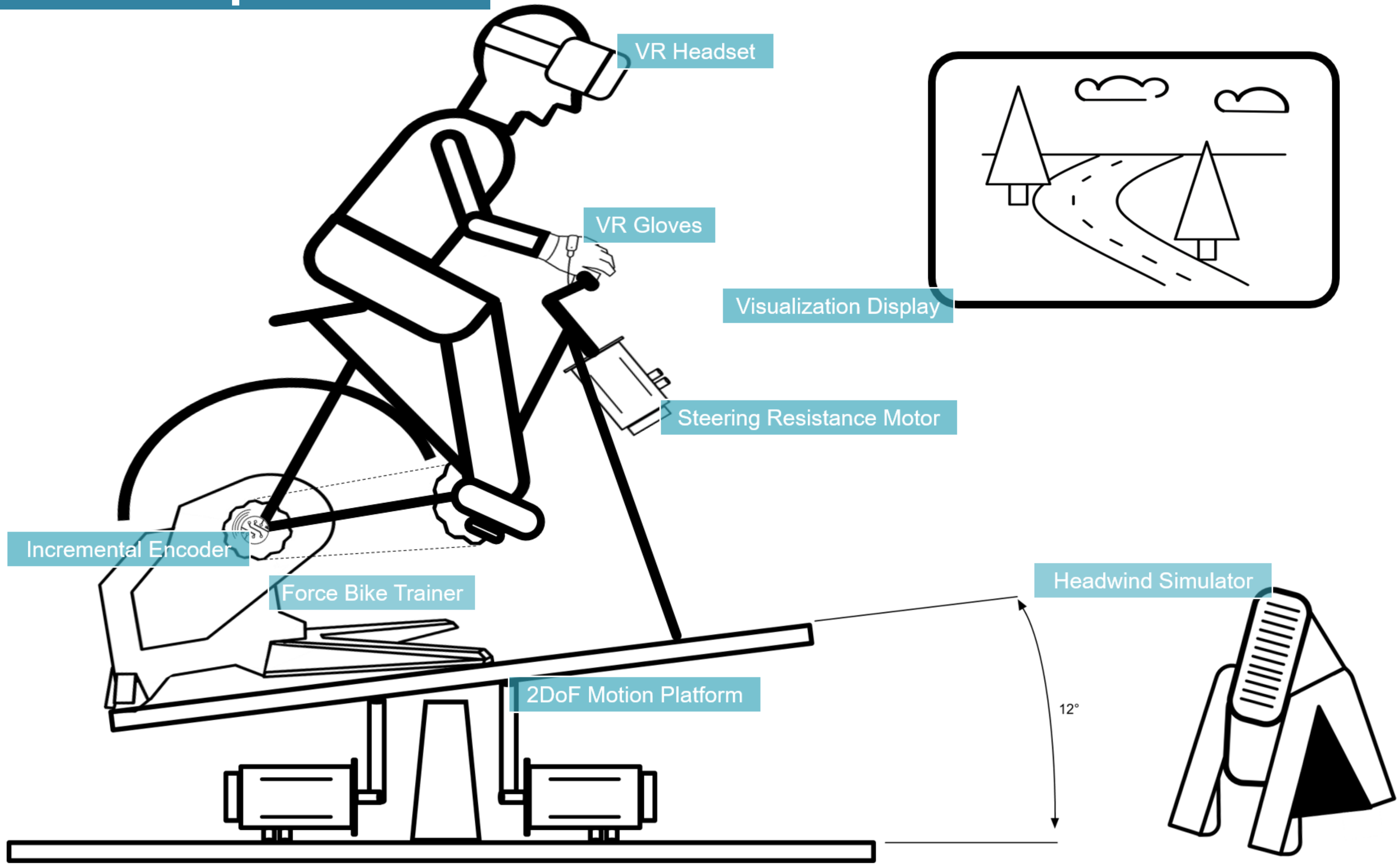
1. Bike Simulator Design

2. Studies and Issues

3. Upgrades to the simulator

4. Outlook

BikeSim Components



BikeEval1

DLR

1. Training (< 5 min)
2. Block A/B
3. Break
4. Block B/A

Scenario	Description	Graphical representation
1-A	Driving straight ahead and stopping at the traffic light with crossing vehicle	
1-B	Driving straight ahead and stopping at the traffic light with a vehicle driving straight ahead	
1-C	Driving straight ahead and stopping at the traffic light without a vehicle	
2	Turning to the right and avoiding a construction site without a vehicle	

Bicycle
Car

Parameter	Description	Profile A	Profile B
Yaw Rate	Factor between the calculated yaw rate, coming from the dynamic model and the applied yaw rate in the virtual reality visualization	0.5	1
Roll	Factor between the measurement of the slope from the motion platform and the virtual reality visualization	2	1.5

@City

eHMI Detection

Issues

Training

- Participants are too overwhelmed with VR and the simulator itself
- More training required on different track than the main track

Technical Issues

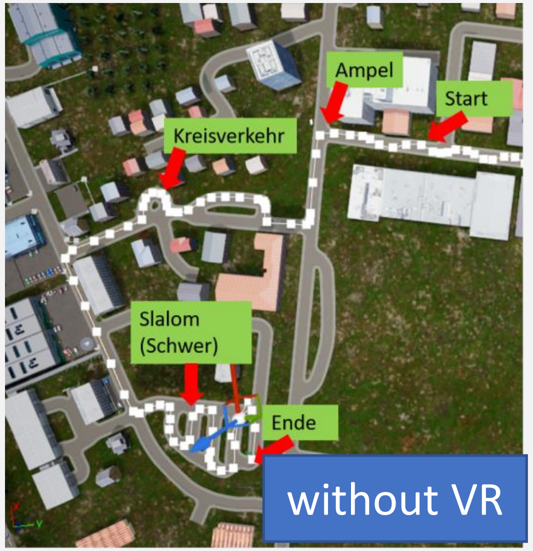
- Controlling the brakes: “it took to long to detect changes in the forward velocity”
- Steering: “didn’t feel right”
  - Too much steering resistance and damping
- Leaning wasn‘t used much
  - Force based leaning wasn‘t very pleasant for the participants due to lack of control
- Heat development and sweat

Study Design

  - Create scenarios, where the simulators features are more demanding

Training Upgrades

Training Part 1 ~ 5 Min.



without VR

Training Part 2 ~ 10 Min.

with VR

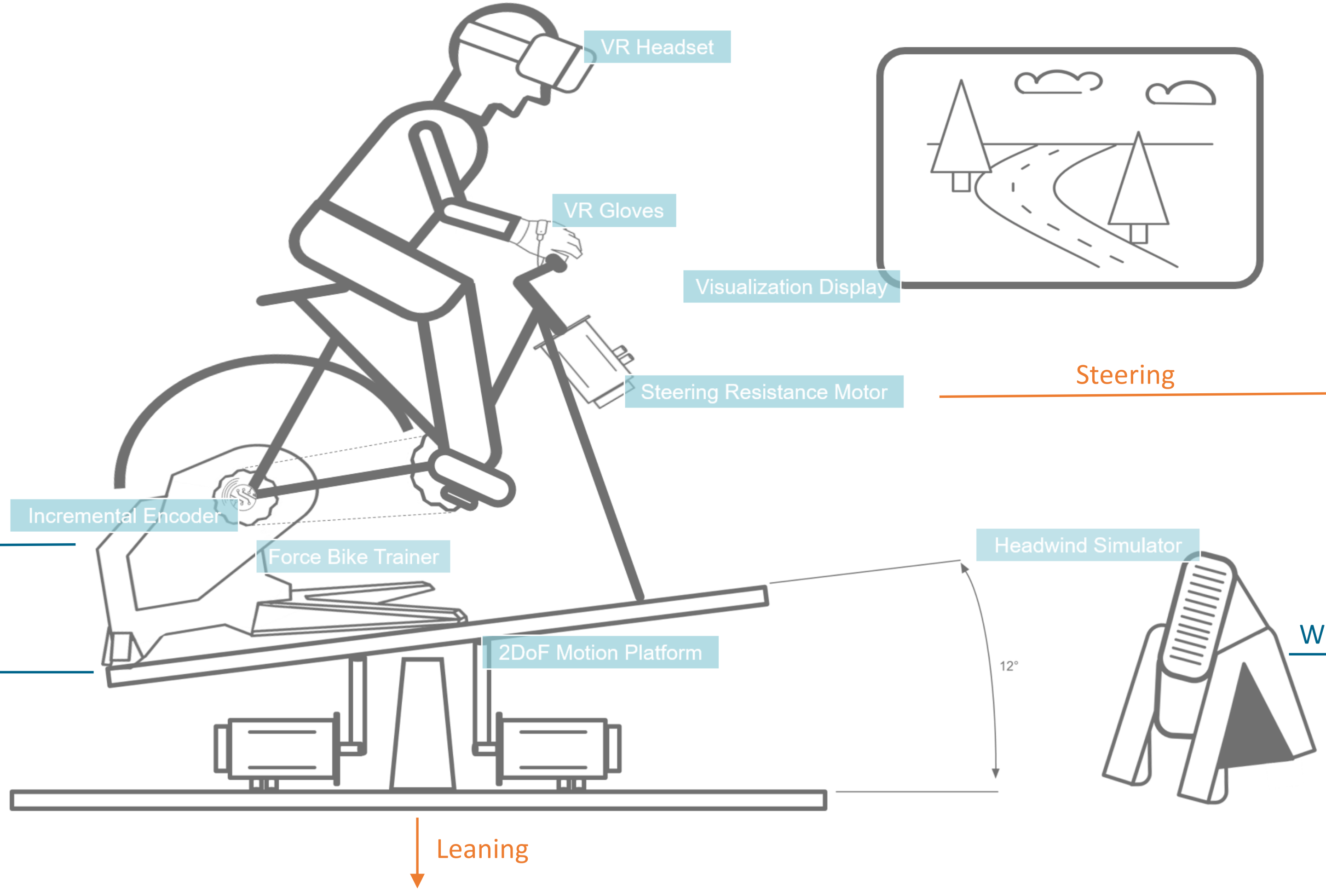
Simulator versions

V1.1

V2.0

Longitudinal

Lateral



Look-up table with adapted vehicle dynamics steering forces

Whipple-bicycle physics model

Bike trainer

Incremental encoder

V brake + Bike trainer information

Disc brake + Incremental encoder information

Static

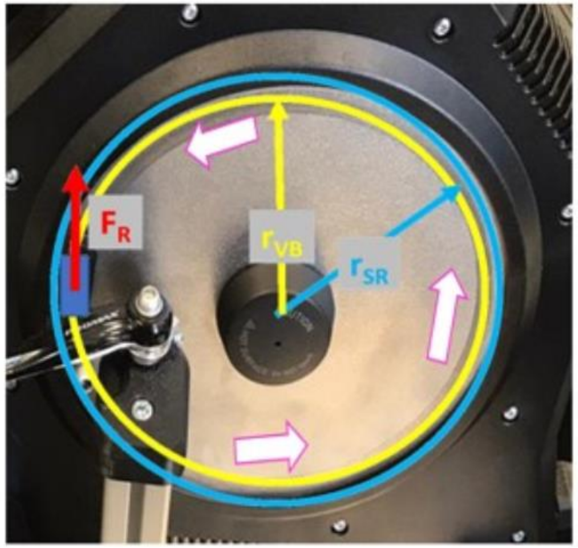
Dynamic (Velocity-dependent)

Force control

Position control

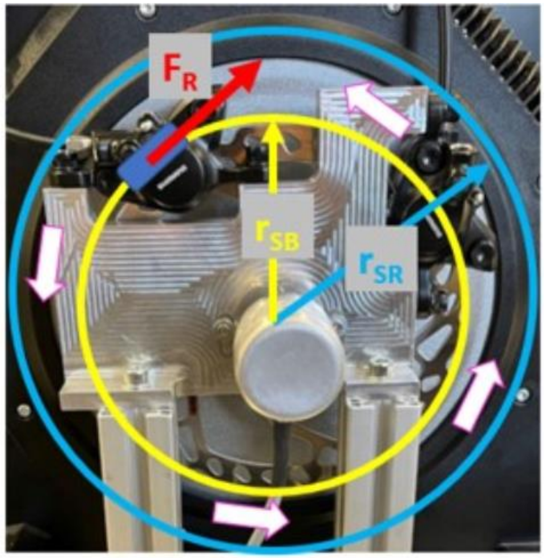
Brake system

V1.1 / V2.0 comparison

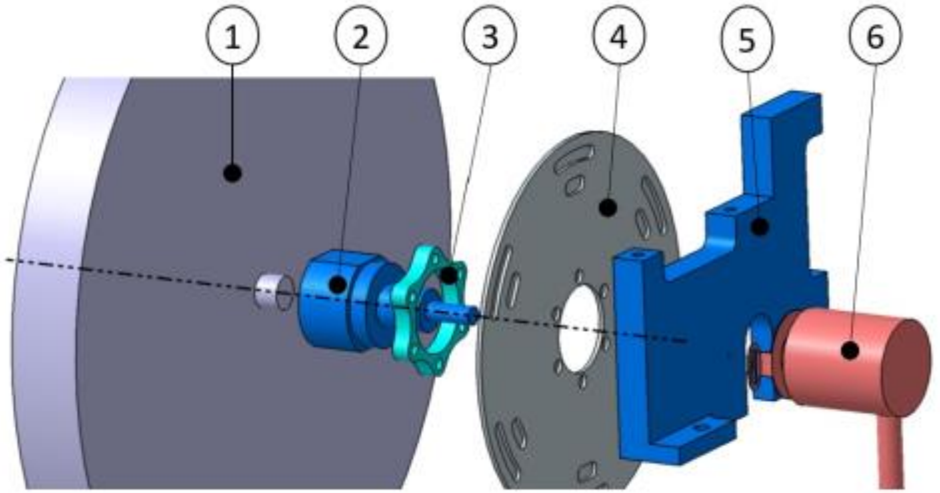


V1.1

vs.



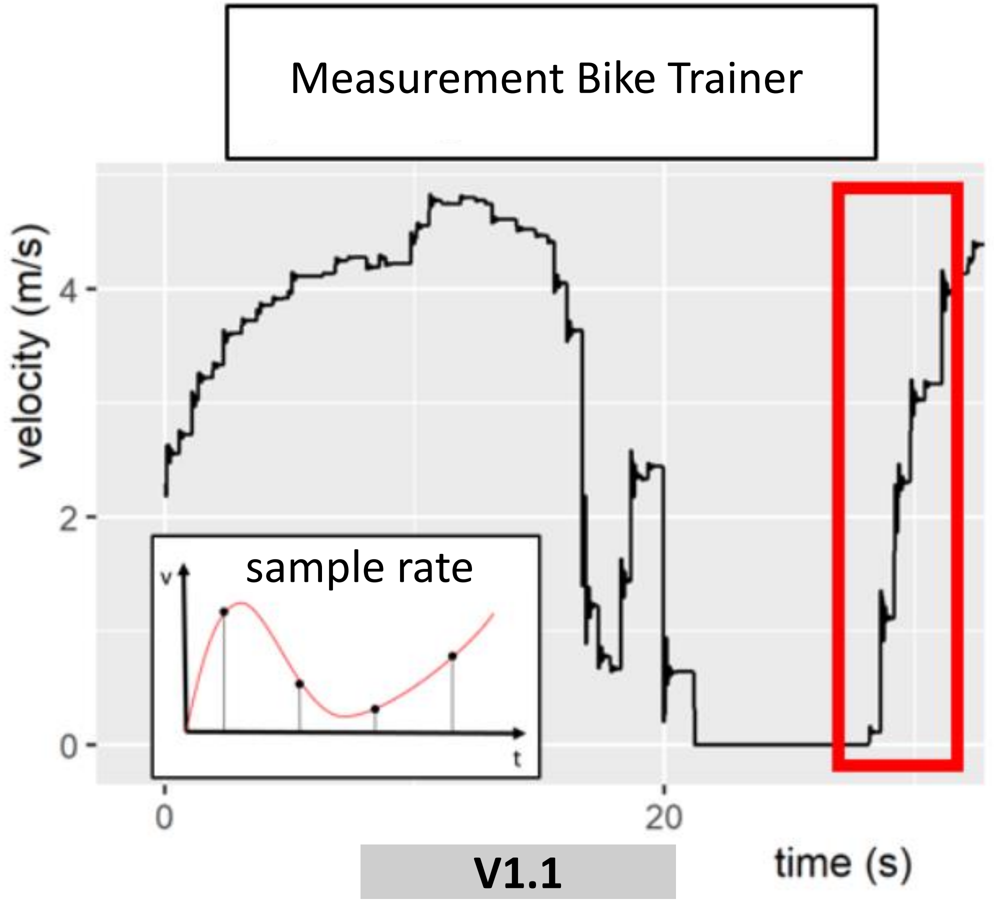
V2.0

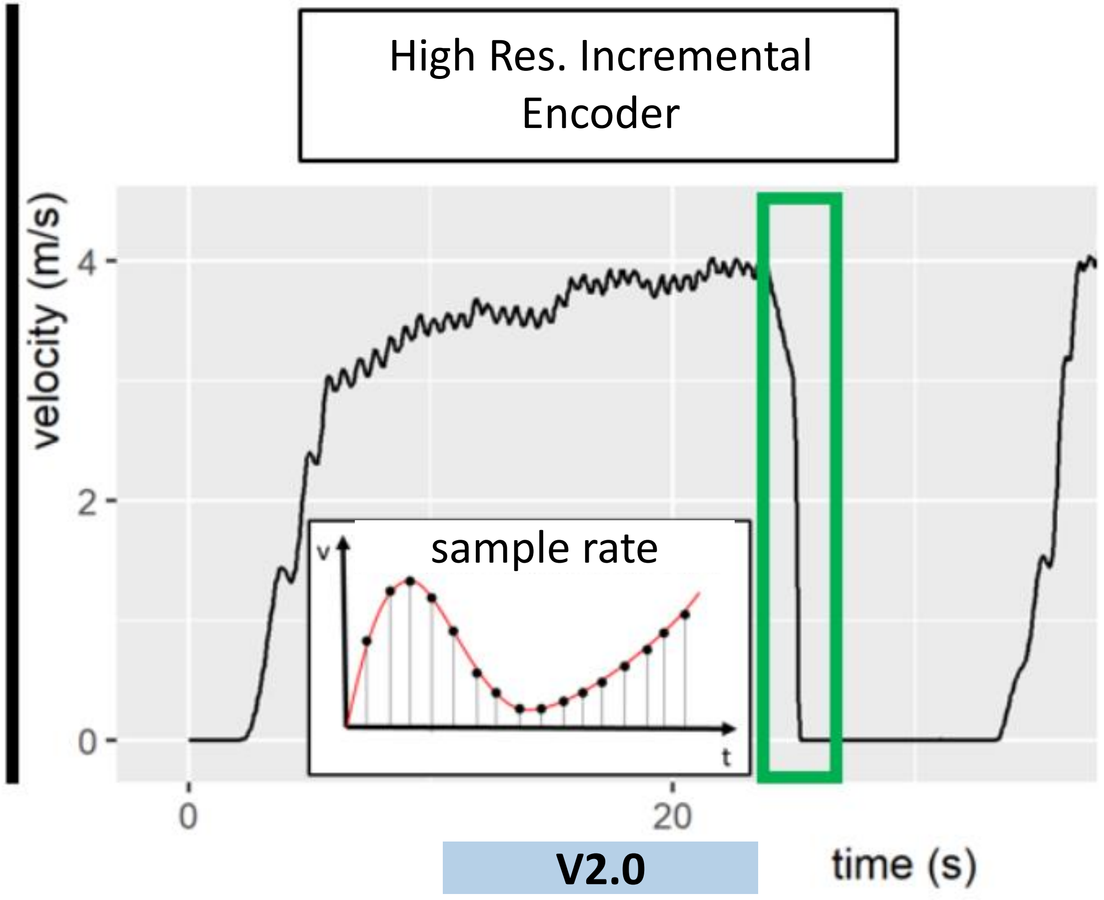


Nr.	Component
1	Flywheel
2/3	Mounting adapters
4	Disc brake
5	Mounting plate (Motion Platform)
6	Incremental encoder

Velocity Measurement

V1.1 / V2.0 comparison

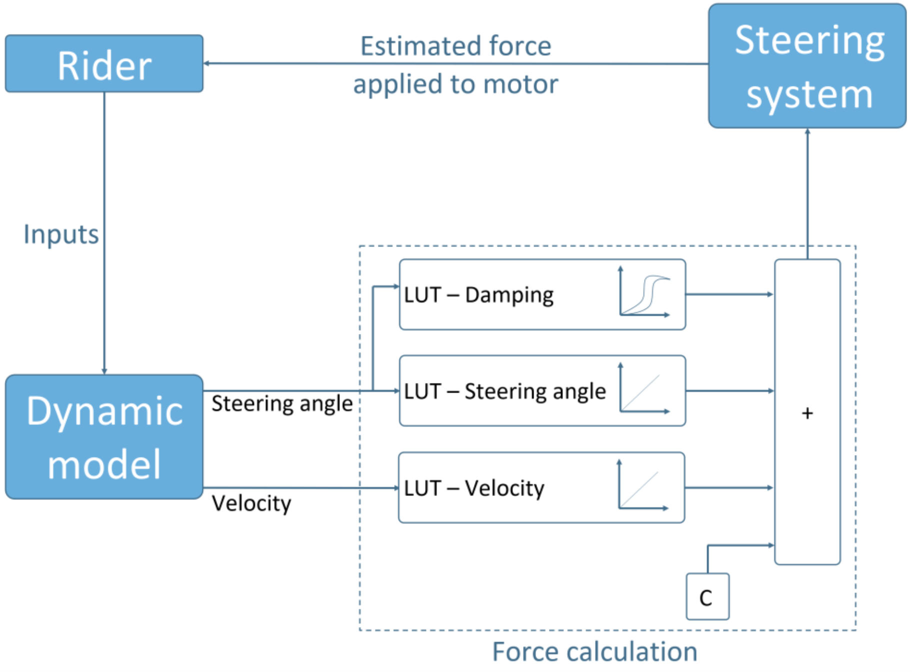




Steering

V1.1 / V2.0 comparison

LUT - Approach



V1.1

Whipple Bicycle Model

From Whipple-bicycle model [1, 2]

$$M\ddot{q} + C\dot{q} + Kq = M\ddot{q} + vC_1\dot{q} + (gK_0 + v^2K_2)q = f$$

with the time-varying quantities: $q = (\phi, \delta)^T$ *and* $f = (T_\phi, T_\delta)^T$

Force feedback T_f:

$$T_f = -(M_{\delta\phi}\ddot{\phi} + C_{\delta\phi}\dot{\phi} + C_{\delta\delta}\dot{\delta} + K_{\delta\phi}\phi + K_{\delta\delta}\delta)$$

V2.0

1, Meijaard, J. P., Papadopoulos, J. M., Ruina, A., & Schwab, A. L. (2007). Linearized Dynamics Equations for the Balance and Steer of a Bicycle: A Benchmark and Review. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *463*, 1955–1982. https://doi.org/10.1098/rspa.2007.1857

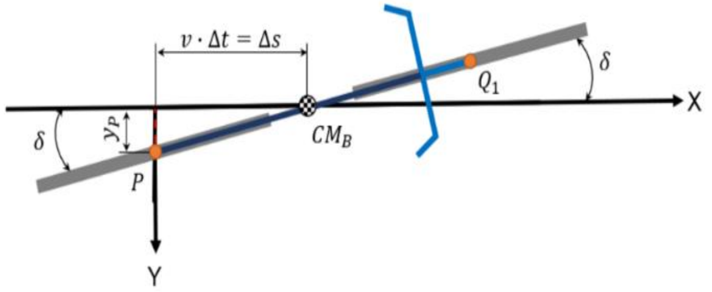
2. Schwab, A. L., & Recuero, A. M. (2013). Design and experimental validation of a haptic steering interface for the control input of a bicycle simulator. Proceedings of the ECCOMAS Thematic Conference on Multibody Dynamics 2013, 103–110.

Leaning

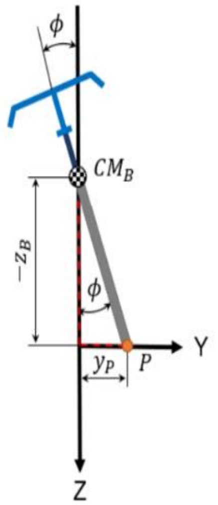
V2.0 Method

V2.0

Not possible to measure the applied leaning moment of the driver T_{B_ϕ} required for the calculation with whipple



(adapted from Astrom et al., 2005; Meijaard et al., 2007)



Displacement $\boldsymbol{y_P}$ of rear contact point P

$$\sin\delta = \frac{y_P}{\Delta s} = \frac{y_P}{v \cdot \Delta t} \rightarrow y_P = \sin\delta \cdot v \cdot \Delta t$$

Lean angle ϕ

$$\tan\phi = \frac{y_P}{-z_B} \rightarrow \phi = \arctan\left(\frac{y_P}{-z_B}\right)$$

+

Bleeding factor

resets errors in calculation for platform to move smoother

+

Limits

Steering angle: ±3°
Velocity: above 2.5 m/s
Maximum lean angle: ±15°

1, Meijaard, J. P., Papadopoulos, J. M., Ruina, A., & Schwab, A. L. (2007). Linearized Dynamics Equations for the Balance and Steer of a Bicycle: A Benchmark and Review. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *463*, 1955–1982. https://doi.org/10.1098/rspa.2007.1857

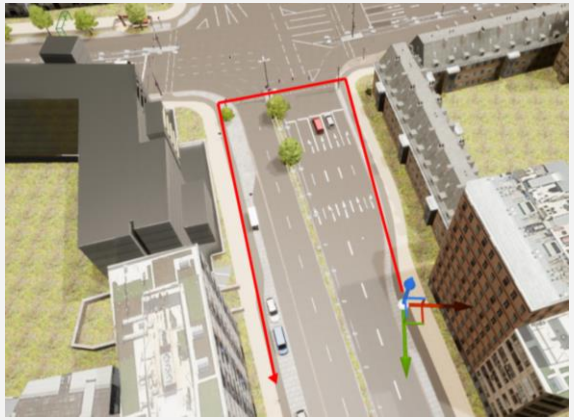
3. Astrom, K. J., Klein, R. E., & Lennartsson, A. (2005). Bicycle Dynamics and Control: Adapted Bicycles for Education and Research. *IEEE Control Systems*, *25*(4), 26–47. https://doi.org/10.1109/MCS.2005.1499389

Scenario Upgrades: BikeEval2

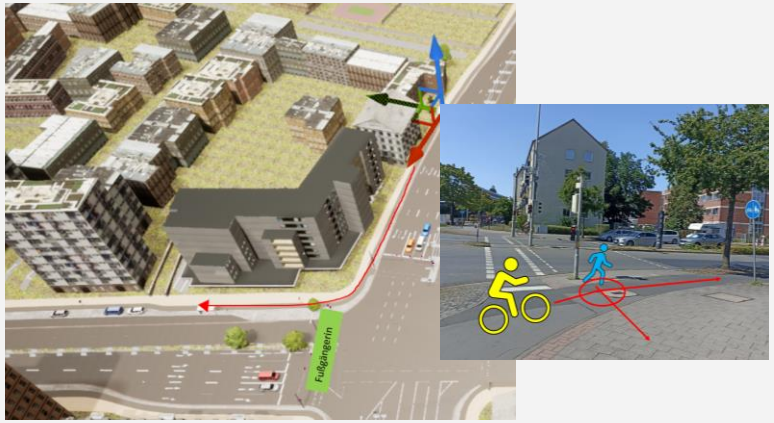
A – Stop at TL + Avoid obstacle

B – Slalom

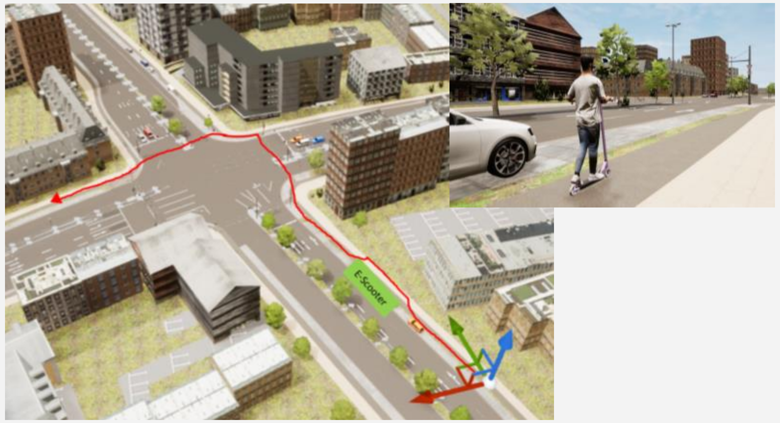
C – „U-Turn“ at Intersection



D – Interaction with pedestrian



E – Overtaking E-Scooter



F – U-Turn / Round-about

Conclusion

Did the improvements work? New Issues

- Training
  - Participants seemed more confident, when confronted with driving tasks
  - Overall low simulator sickness scores, but slightly higher than before
- Technical issues
  - Improvements
    - Accelerating and Braking felt more realistic (but brakes are too strong)
    - Dynamic headwind felt better
  - No significant Difference:
    - Steering resistance felt more realistic
    - Leaning and curves felt less realistic

Outlook

Lateral Improvements

- Leaning behavior improved
  - New Algorithm adapted from TU Wien

$$\alpha_{strong} = \arctan(\frac{v^2}{g * r}) \qquad \alpha_{weak} = \arctan(\frac{0.6 * v^{1.7}}{g * r})$$ [1]

1, Wintersberger, P., Matviienko, A., Schweidler, A. & Michahelles, F. (2022). Development and Evaluation of a Motion-based VR Bicycle Simulator. Proceedings of the ACM on Human-Computer Interaction 6(MHCI):1-19. https://dl.acm.org/doi/10.1145/3546745

Outlook

Training Track

- Standardized Training to keep training experiences of the test persons comparable
- The aim is to initialte as little simulation sickness as possible
- Two variants will be tested:
  - With gamification elements to distract the test subjects
  - Without gamification elements

Thank You

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