Automated Comfortable Docking at Bus Stops

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Project Team

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Agenda

- **Project description.**
- Problem statement.
- The comfort model.
- Optimization problem formulation.
- Results: simulations and experiments.

Project Description

Bus stop docking

1

Depot process

2

Bus train

3

City bus automation - bus trains, bus stop docking and depot processes: https://research.chalmers.se/en/project/7841

Project Description

Bus stop docking 1

Depot process 2

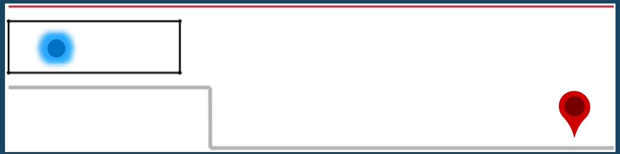
Bus train 3

Project Description

Bus stop docking

1

1.1. Autonomous docking (geometric constraints): accepted paper at ECC21.



1.2. Automated comfortable docking (comfort constraints)

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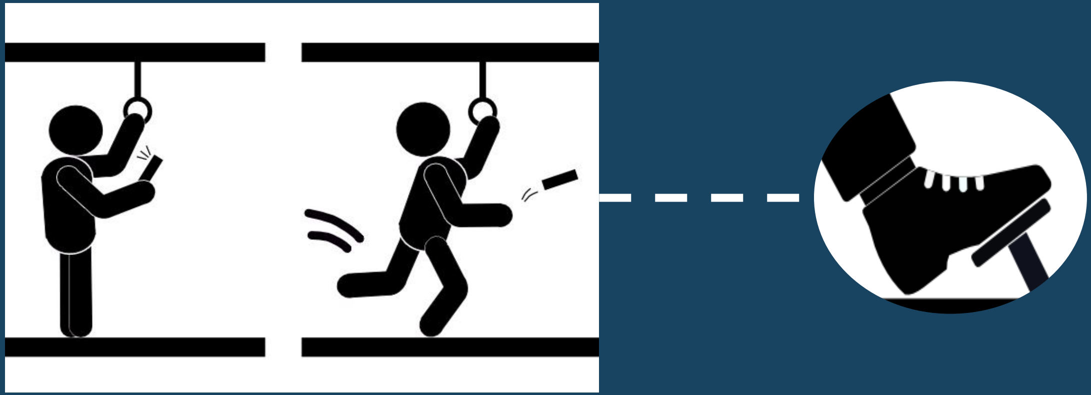
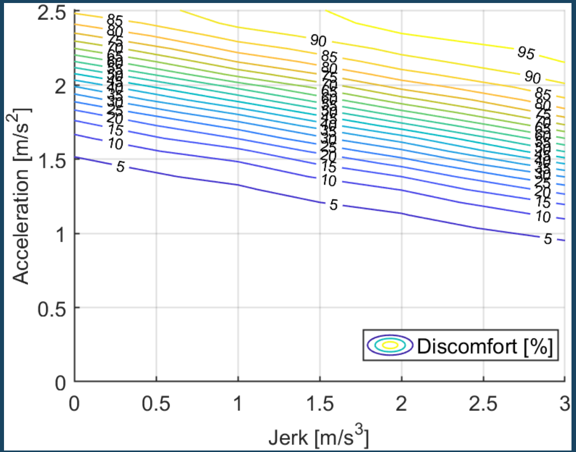
Why optimizing comfort?

- System performance (e.g., fuel consumption, parking time) can be improved by higher acceleration/deceleration than normal.
- However, the risk of passengers losing their balance is increased, especially for standing passengers.



Why optimizing comfort?

- System performance (e.g., fuel consumption, parking time) can be improved by accelerating/decelerating.
- However, the risk of passengers losing their balance is increased, especially for standing passengers.
- Ride comfort is a combined effect of acceleration and jerk (coupled).
- A comfort model is needed.



Acceptability of discomfort rated by passengers given in percentage. The higher is the least acceptable. [1]

[1]. Powell, Jonathan P., and R. Palacín. "Passenger stability within moving railway vehicles: limits on maximum longitudinal acceleration." *Urban Rail Transit* 1.2 (2015): 95-103.

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The comfort model

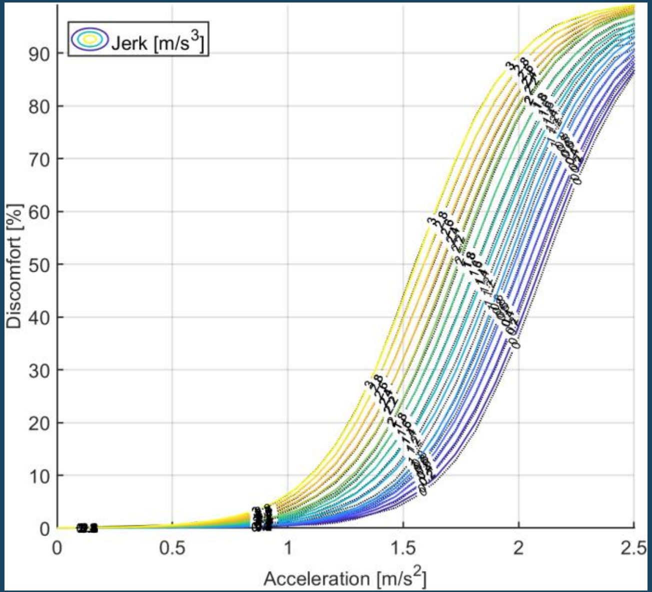
- Derived by fitting the data in [1] to a curve.
- Resulting curve: a function that couples the effect of acceleration and jerk:

$$dis(s,a,j) = \frac{A_2\, Q_1}{A_2 Q_2 + e^{-(A_1 Q_3).a}}$$

$A_1 = [\mathbf{1}\,, j, j^2\,]$
$A_2 = [\mathbf{1}\,, j, j^2\,, j^3\,]$

Q_1, Q_2, Q_3 : constant coefficient vectors

s, a, j : point on path, acceleration, and jerk



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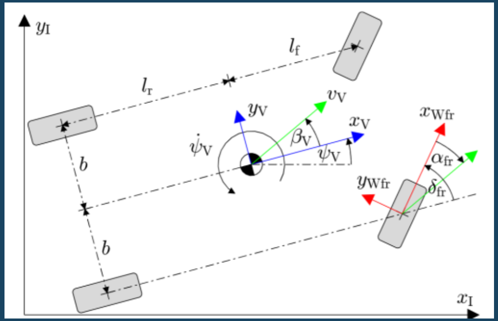
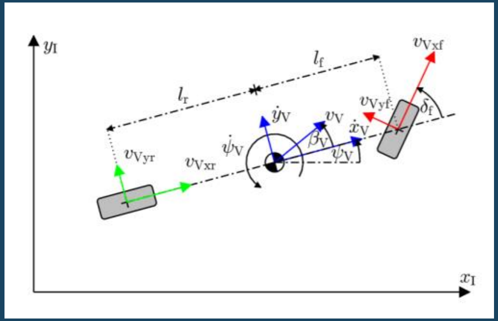
The Vehicle model

- Kinematic bicycle model.
- Assumptions: front-steered (city bus), no tire slip (simplification).

4-wheel model



2-wheel model



The bus stop geometry

- Location: at Arendals Skans bus charging station.

Start

End

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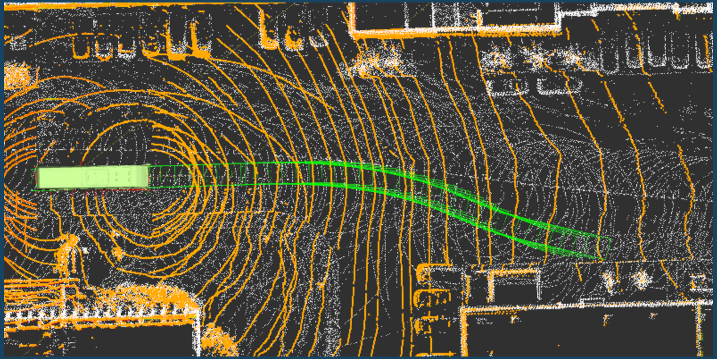
The bus stop geometry

Arendals Skans bus stop (Google maps)


Path as seen from the bus navigation system

The Optimal Control Problem (OCP)

- The objective function minimizes:

$$J(\boldsymbol{x}, \boldsymbol{u}, z) = \left\| \boldsymbol{x}(s_f) - \boldsymbol{x}_f \right\|_{Q_f}^2 + z + \int_0^{s_f} \|u(s)\|_R^2 \cdot ds$$

Deviation from a target final state — Discomfort — Actuator usage

Q_f, R: weighting matrices

The Optimal Control Problem (OCP)

- The objective function.
- The nonlinear control problem (NLP)

$$\min_{u} \tilde{J}(\boldsymbol{x}, \boldsymbol{u}, z)$$

subject to

Dynamics ⟵	$x(k+1) = \tilde{f}\big(x(k), u(k)\big), \qquad k = 0, \ldots kf-1$
Road geometry ⟵	$g(x, k) \leq 0, \qquad k = 1, \ldots kf$
States and inputs {	$x_{min}(k) \leq x(k) \leq x_{max}(k), \qquad k = 1, \ldots kf$
	$u_{min}(k) \leq u(k) \leq u_{max}(k), \qquad k = 0, \ldots kf-1$
Discomfort ⟵	$\xi_{min}(k) \leq \xi(k) \leq \xi_{max}(k), \qquad k = 0, \ldots kf-1$
Initial states ⟵	$x(0) = x_0$

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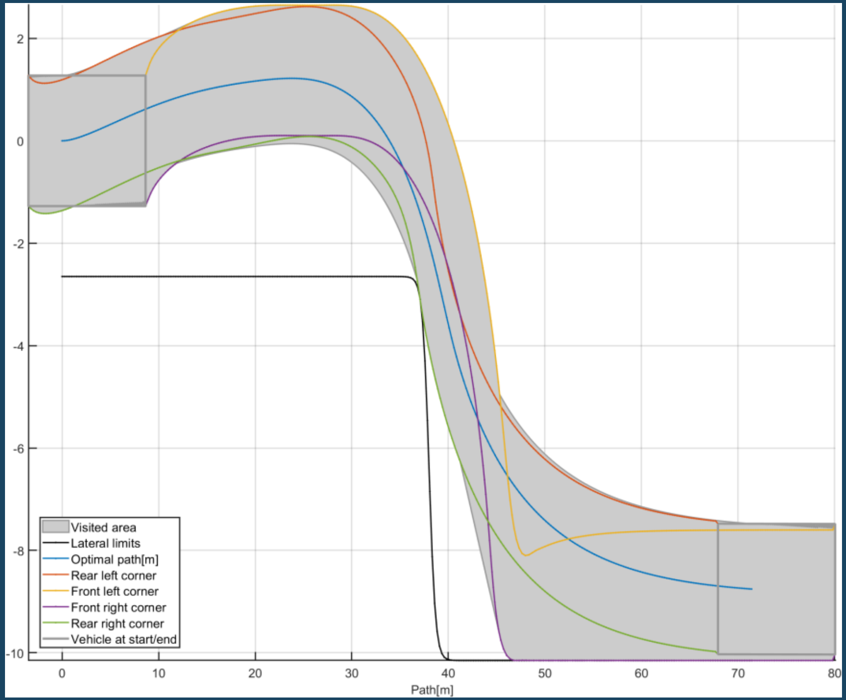
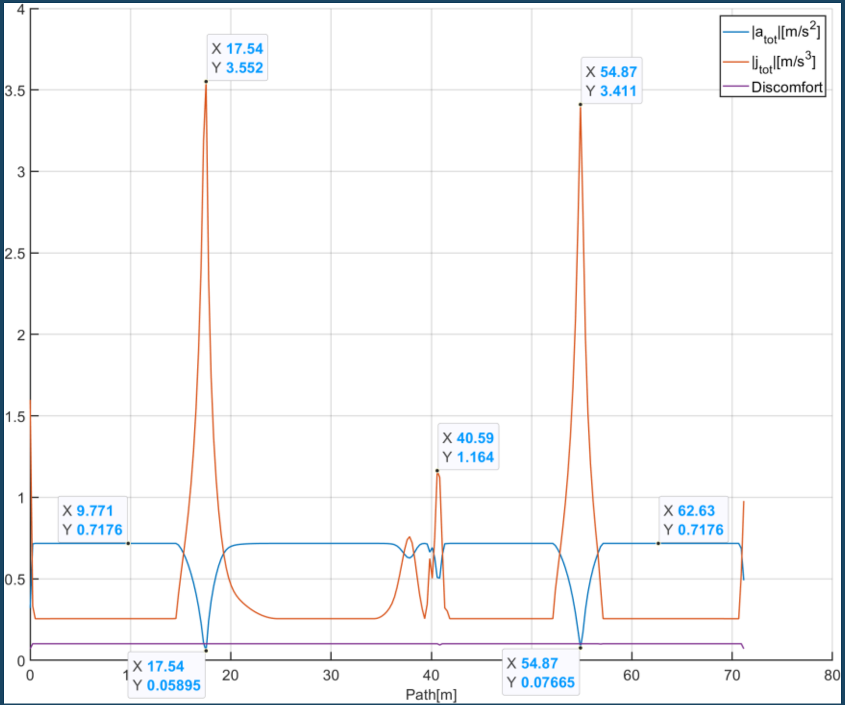
Simulation results

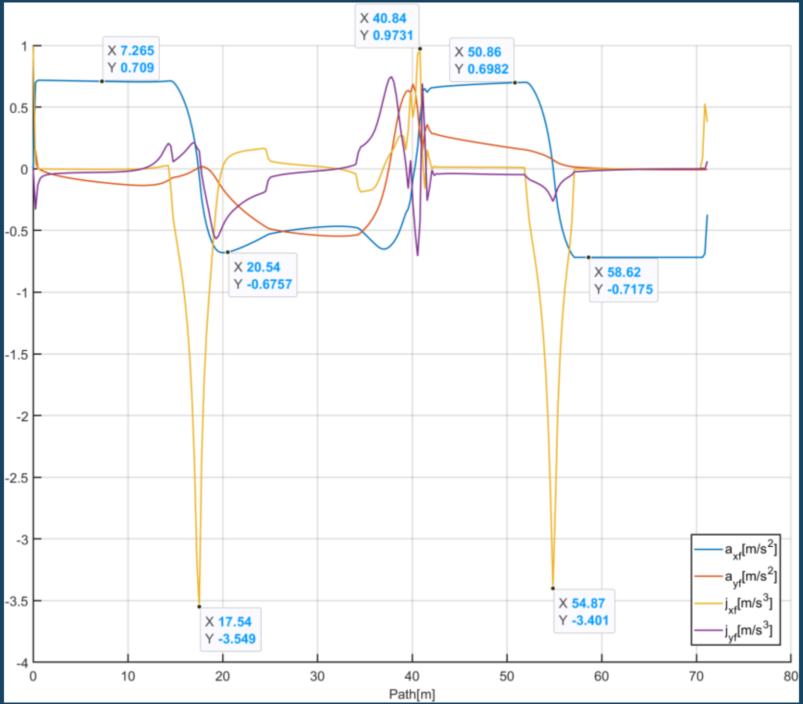


Simulated optimized trajectory

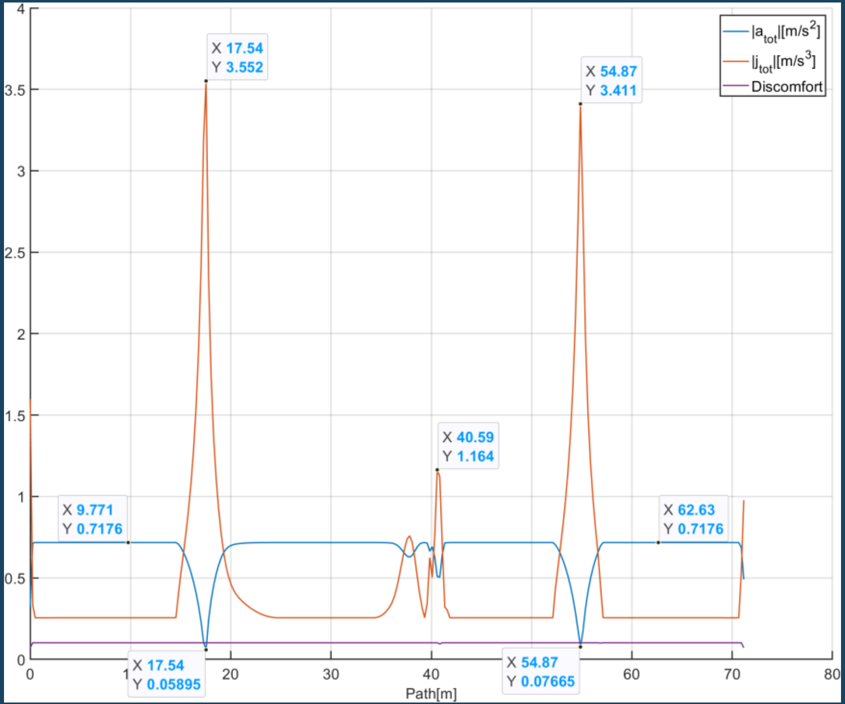


Total acceleration, total jerk, and discomfort profile

Simulation results

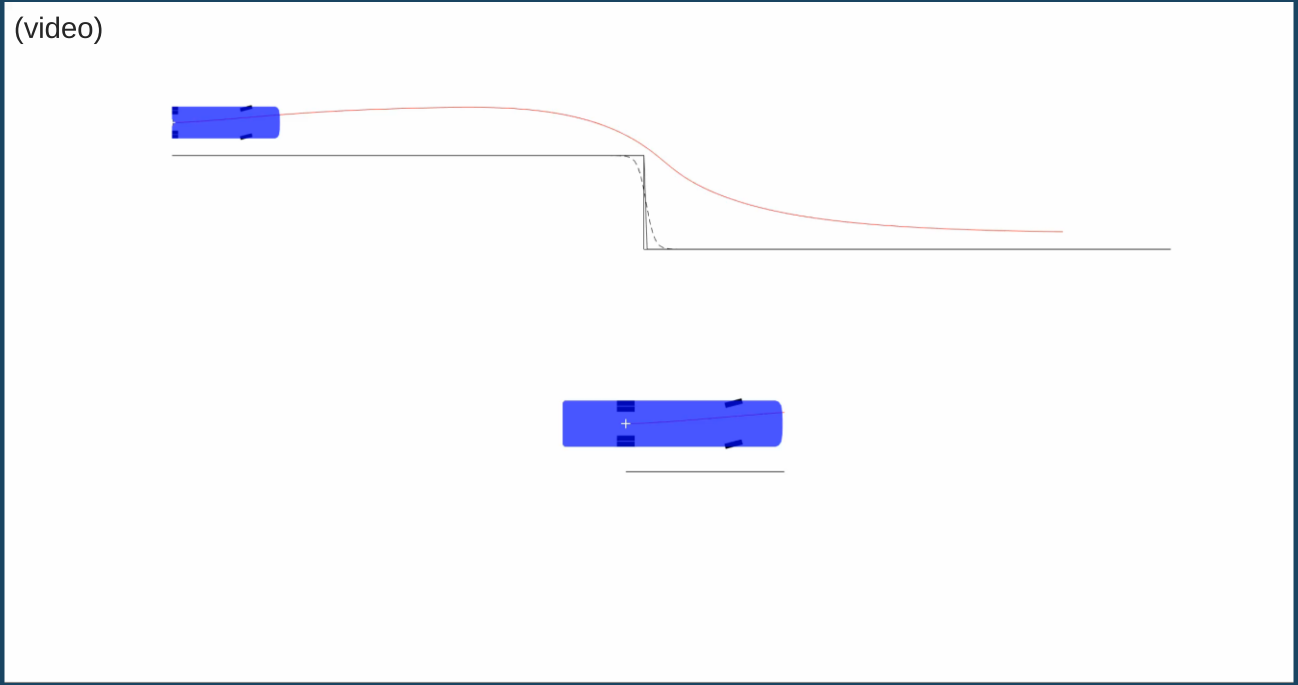


Acceleration and jerk (longitudinal and lateral)



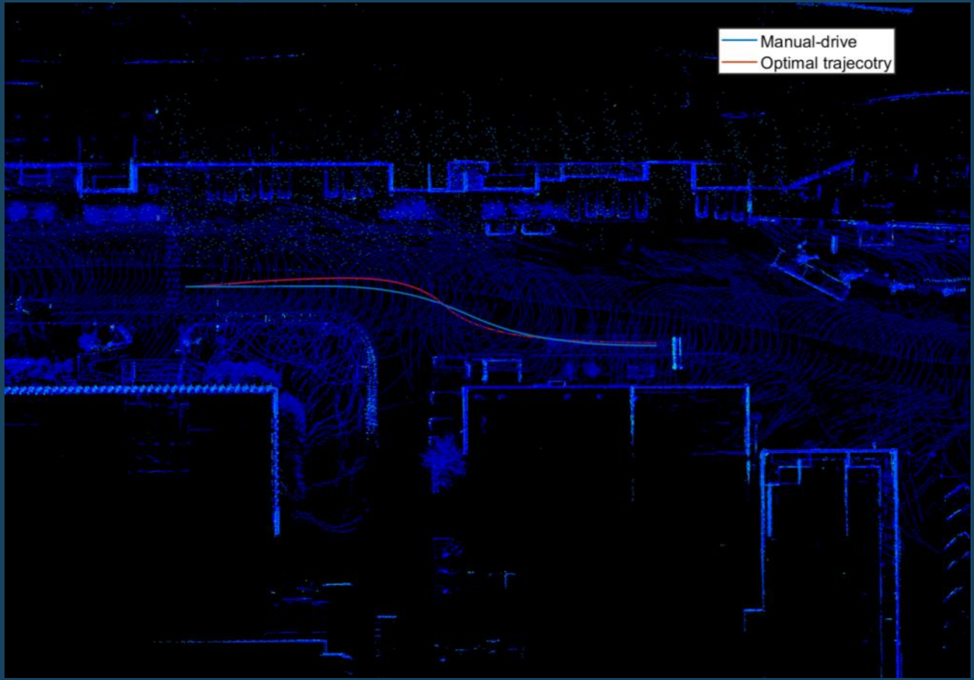
Total acceleration, total jerk, and discomfort profile

Simulation results

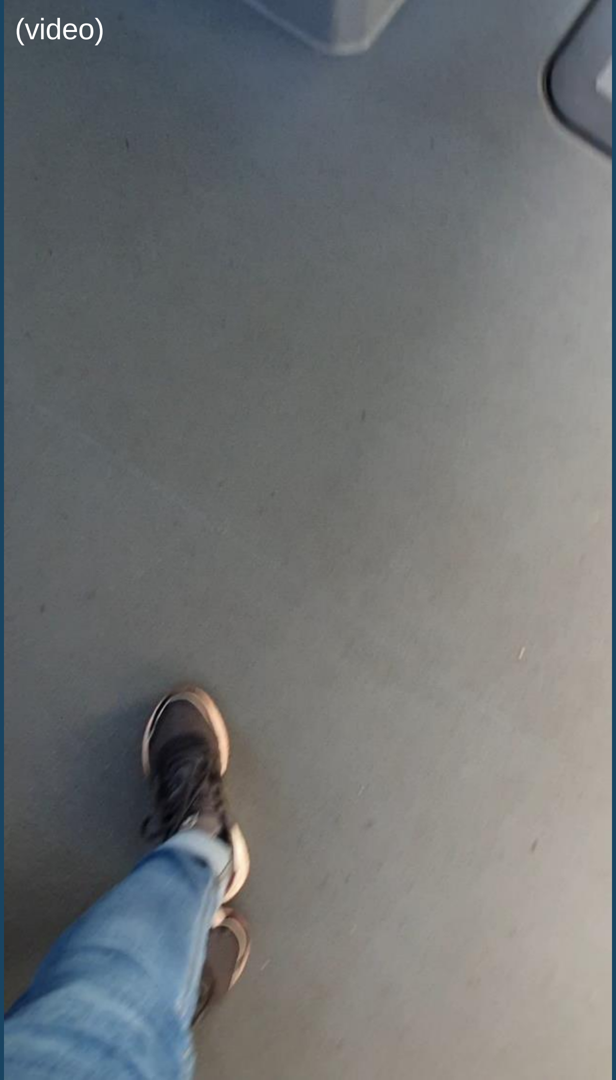


Experiments

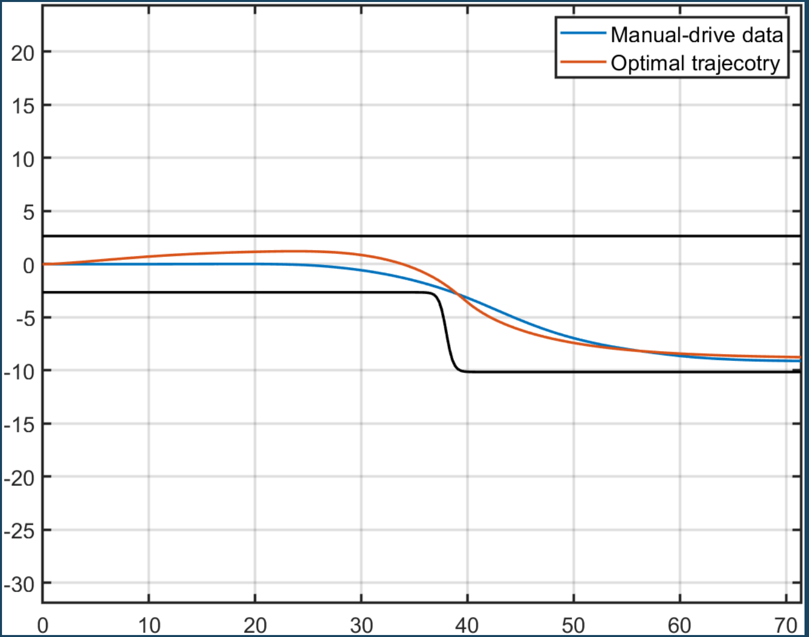
The autonomous trajectory was loaded, and comfort was assessed by 2 passengers standing approximately at the middle of the bus.
(see the video)



(video)

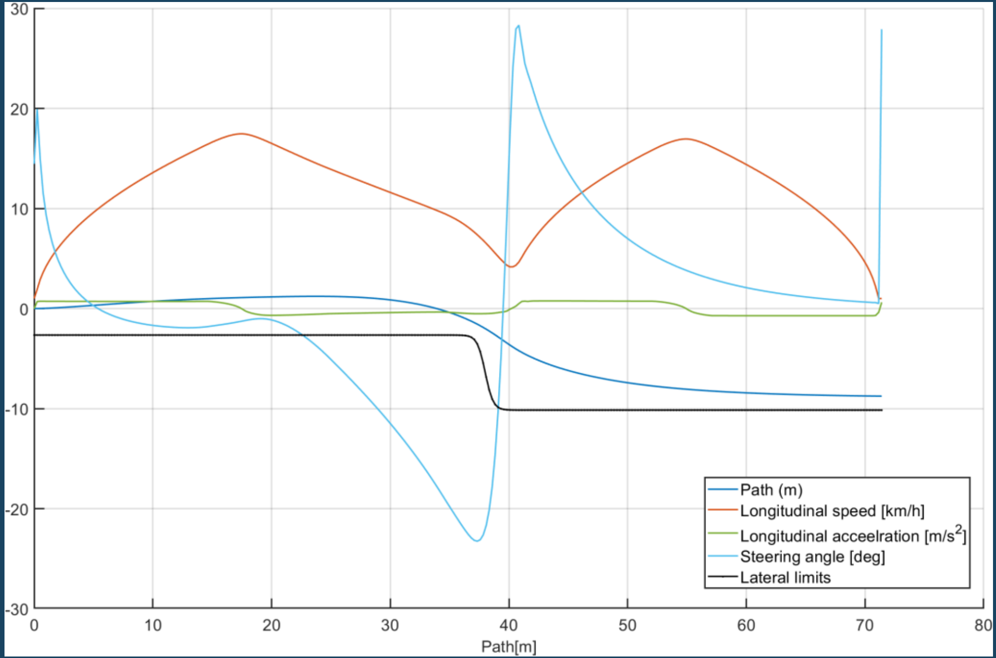


Optimal vs. manual drive

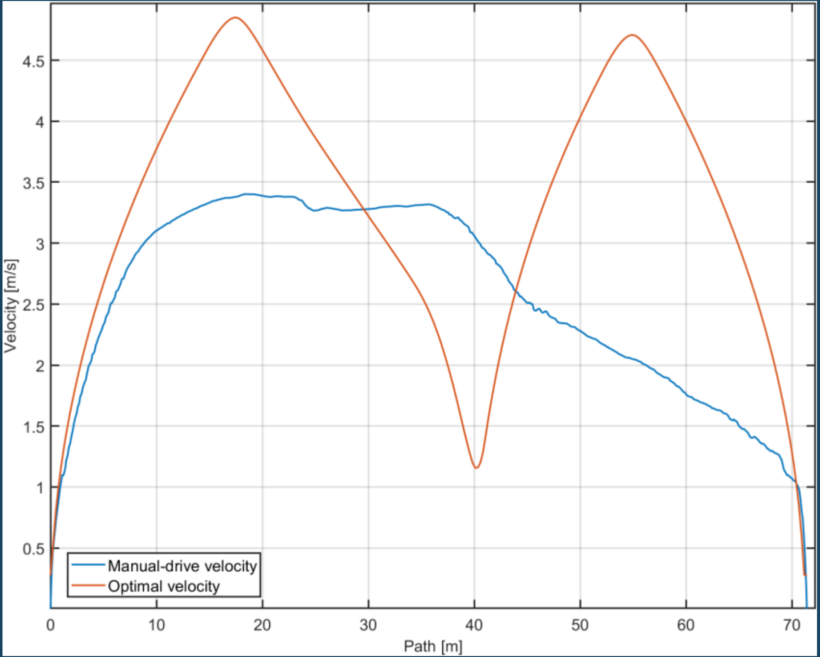


Manual vs. optimal trajectory

Optimal vs. manual drive



Simulation: notice the speed profile around the beginning of the bus stop



Speed profile of manual vs. optimal trajectory

How to proceed from here?

- Plans are made for further tests at Volvo, to log the acceleration data.
- A quantitative evaluation of the discomfort is needed, to compare simulations to experimental data.

Acknowledgements

- This project is supported by the Swedish State Innovation Agency, VINNOVA and Region Västra Götaland.
- Special thanks to **Joakim Jonasson** from Volvo Buses for technical support and bus operation.

Thank you!

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