Model Predictive Control based Driver Support for Docking of Articulated Vehicles at Logistics Areas

Abram Dekker [1], Jason van Kolfschoten [2], Karel Kural [2], Laura Ferranti [1], Jan Benders [2]

[1]Delft University of Technology, Netherlands

[2]HAN University of Applied Sciences, Netherlands

TU Delft

HAN_UNIVERSITY OF APPLIED SCIENCES

AVEC'22

This project has received funding from the European Commission under grant agreement No 952189.

Content

- Introduction & Context
- Controller Requirements and Interfaces
- Controller Structure
- Controller Implementation and Verification
- Conclusions and Research Outlook

Current Situation at many distribution centres (4 x Faster)

AVEC'22

Driver Challenges

- Limited field of view
- Controlling naturally unstable system
- Limited manoeuvrability space
- Keep the safety on first place under the high pressure of productivity

HAN_UNIVERSITY OF APPLIED SCIENCES

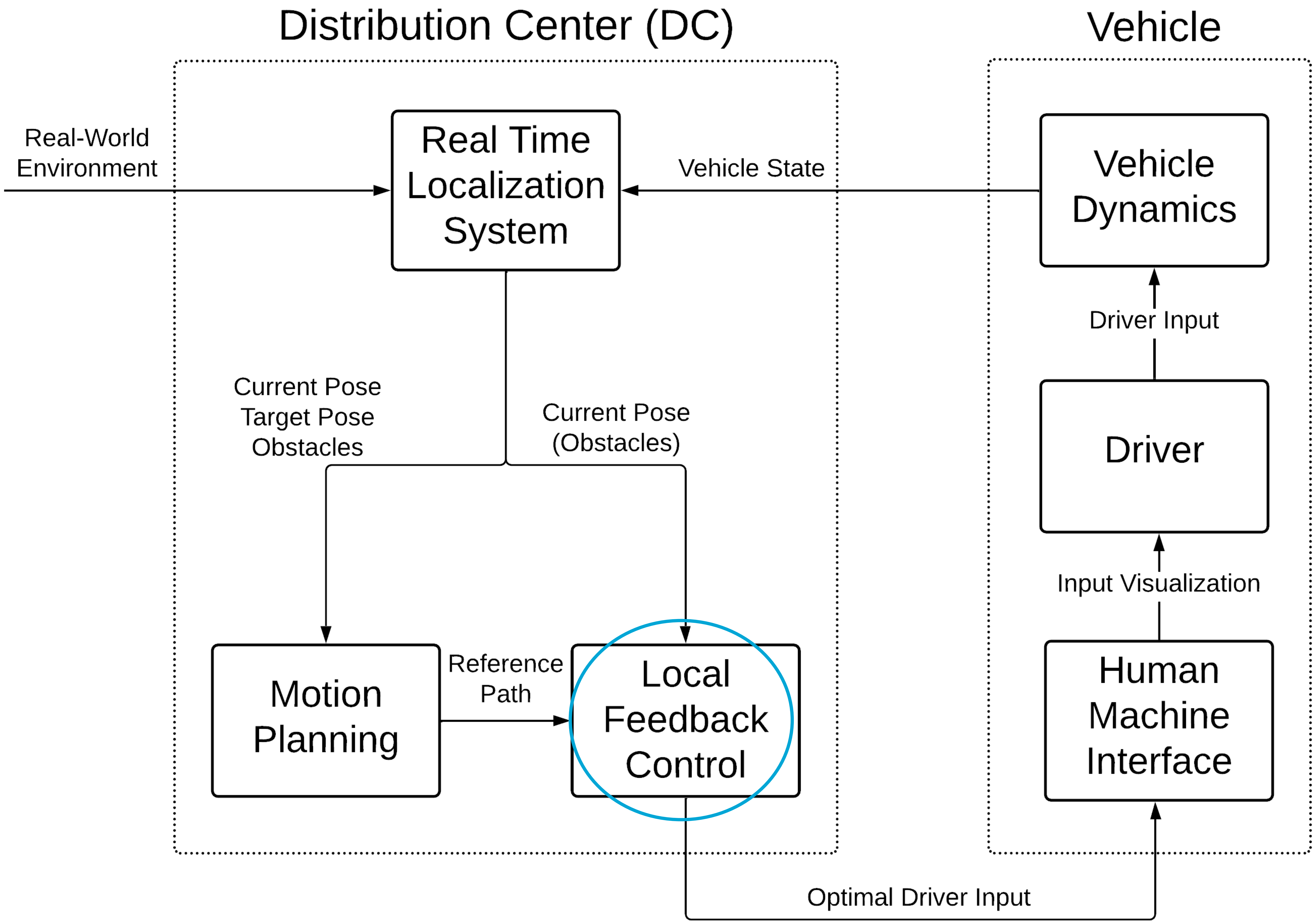
VISTA

VIsion **S**upported **T**ruck docking **A**ssistant.

HAN_UNIVERSITY
OF APPLIED SCIENCES

System Architecture

AVEC'22

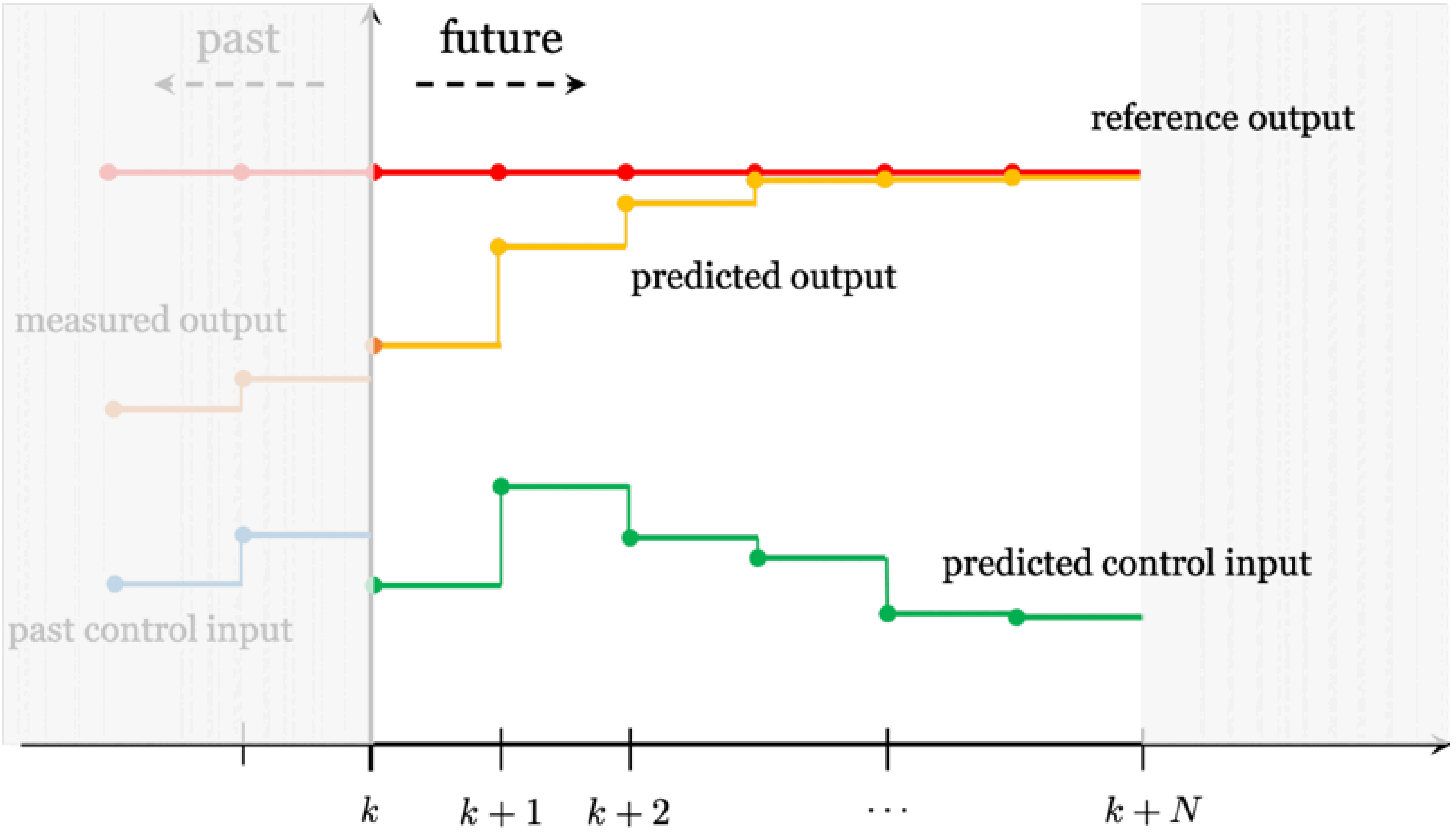


HAN_UNIVERSITY OF APPLIED SCIENCES

Path Tracking Controller requirements

- Ability to incorporate driver (model) behaviour as imperfect actuator
- Robustness against the disturbances and constraints
- Bi-directional functionality

- Choice: Receding Horizon Control (RHC), also known as Model Predictive Control (MPC)

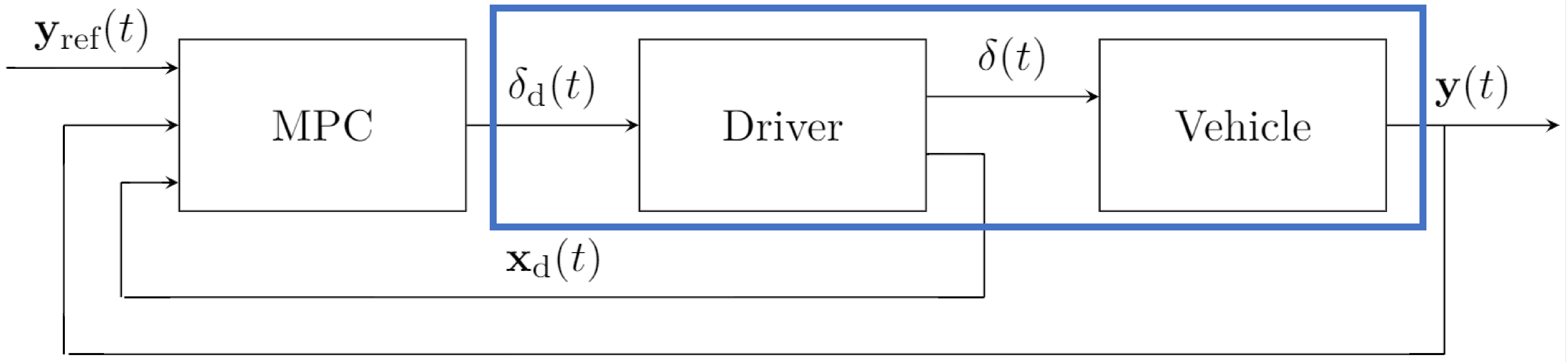


embotech

FORCESPRO

Optimization Problem

- Cost function
- System dynamics
- Constraints



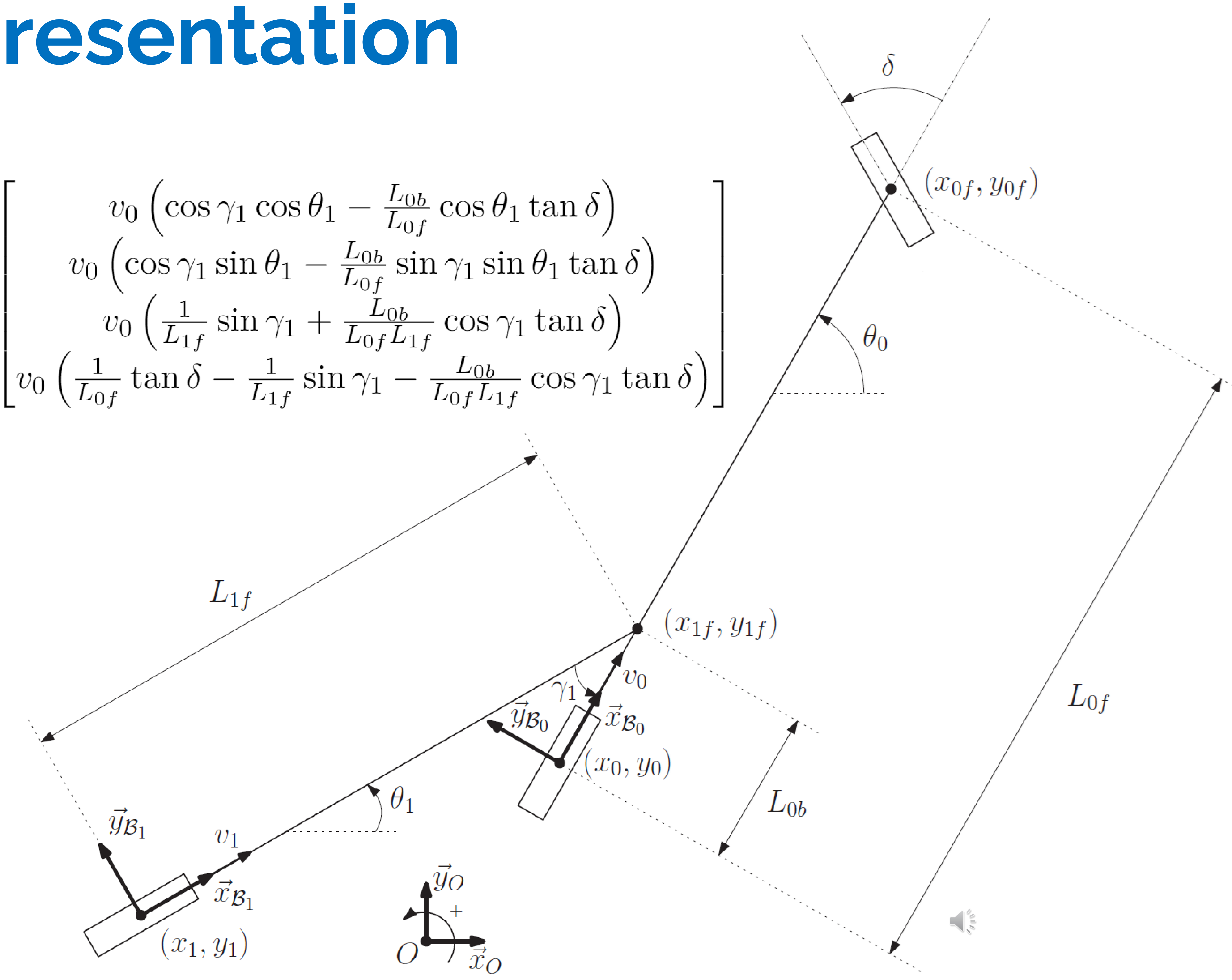
$$\min_{\mathbf{u}(0),\mathbf{u}(1),\ldots,\mathbf{u}(N-1)} \sum_{k=0}^{N} J(\mathbf{x}(k), \mathbf{u}(k)),$$

$$\begin{aligned} \text{s.t.} \quad & \mathbf{x}(0) = \mathbf{x}_{\mathrm{init}}, \\ & \mathbf{x}(k+1) = f(\mathbf{x}(k), \mathbf{u}(k)) && \forall k \in \{0, 1, \ldots, N-1\}, \\ & g(\mathbf{x}(k), \mathbf{u}(k)) = 0 && \forall k \in \{0, 1, \ldots, N\}, \\ & h(\mathbf{x}(k), \mathbf{u}(k)) \leq 0 && \forall k \in \{0, 1, \ldots, N\}. \end{aligned}$$

Vehicle Behaviour Representation

- Kinematic model of single articulated vehicle
- Geometry based on envelope of common dimensions of EU Tractor-Semitrailer
- Assumption no tyre slip and inertial effects
- Validity only at low speeds

$$\dot{\mathbf{x}}(t) = \begin{bmatrix} v_0 \left(\cos\gamma_1 \cos\theta_1 - \frac{L_{0b}}{L_{0f}} \cos\theta_1 \tan\delta\right) \\ v_0 \left(\cos\gamma_1 \sin\theta_1 - \frac{L_{0b}}{L_{0f}} \sin\gamma_1 \sin\theta_1 \tan\delta\right) \\ v_0 \left(\frac{1}{L_{1f}} \sin\gamma_1 + \frac{L_{0b}}{L_{0f}L_{1f}} \cos\gamma_1 \tan\delta\right) \\ v_0 \left(\frac{1}{L_{0f}} \tan\delta - \frac{1}{L_{1f}} \sin\gamma_1 - \frac{L_{0b}}{L_{0f}L_{1f}} \cos\gamma_1 \tan\delta\right) \end{bmatrix}$$

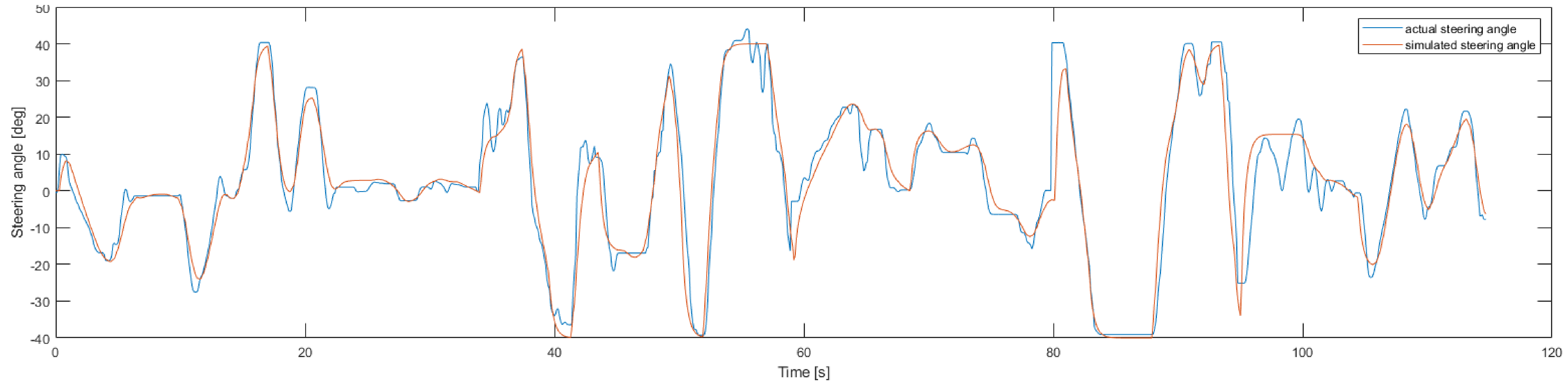


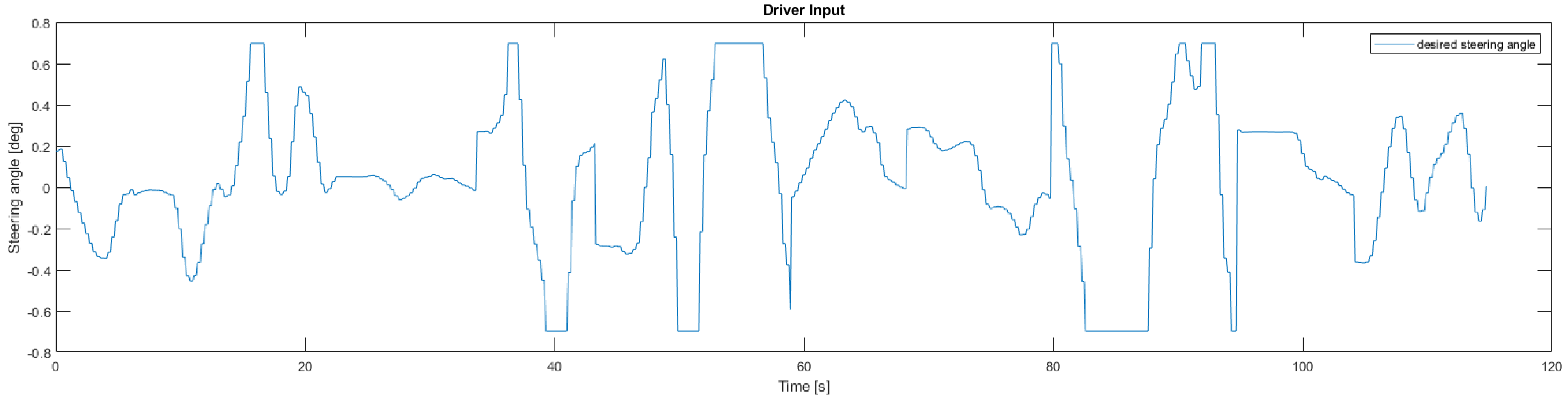
Driver Behaviour Representation

- McRuerer model
- 2nd order LTI
- Driver delay compensation

$$H(s) = K \frac{(T_L s + 1)}{(T_l s + 1)(T_N s + 1)} e^{-\tau s}$$

τ = Reaction time delay
T_N = Neuromuscular lag
K, T_L and T_l Adjustable by driver depending on controlled system





- System identification (Interior-point optimization algorithm) used to determine the driver constants

Cost Function Definition $\sum_{k=0}^{N} J(\mathbf{x}(k), \mathbf{u}(k))$

- Reference path tracking
- Reference velocity tracking
- Steer rate suppression

$$J_y(\mathbf{x}(k)) = \left(w_{\mathbf{y}}[x_{1,\mathrm{ref}}(k) - x_1(k)]\right)^2 + \left(w_{\mathbf{y}}[y_{1,\mathrm{ref}}(k) - y_1(k)]\right)^2$$

$$J_u(\mathbf{u}(k)) = \left(w_{v_0}[v_{0,\mathrm{ref}}(k) - v_0(k)]\right)^2$$

$$J_{\Delta u}(\mathbf{u}(k)) = \left(w_{\Delta\delta}[\delta_{\mathrm{d}}(k) - \delta_{\mathrm{d}}(k-1)]\right)^2$$

- Weights tuning*

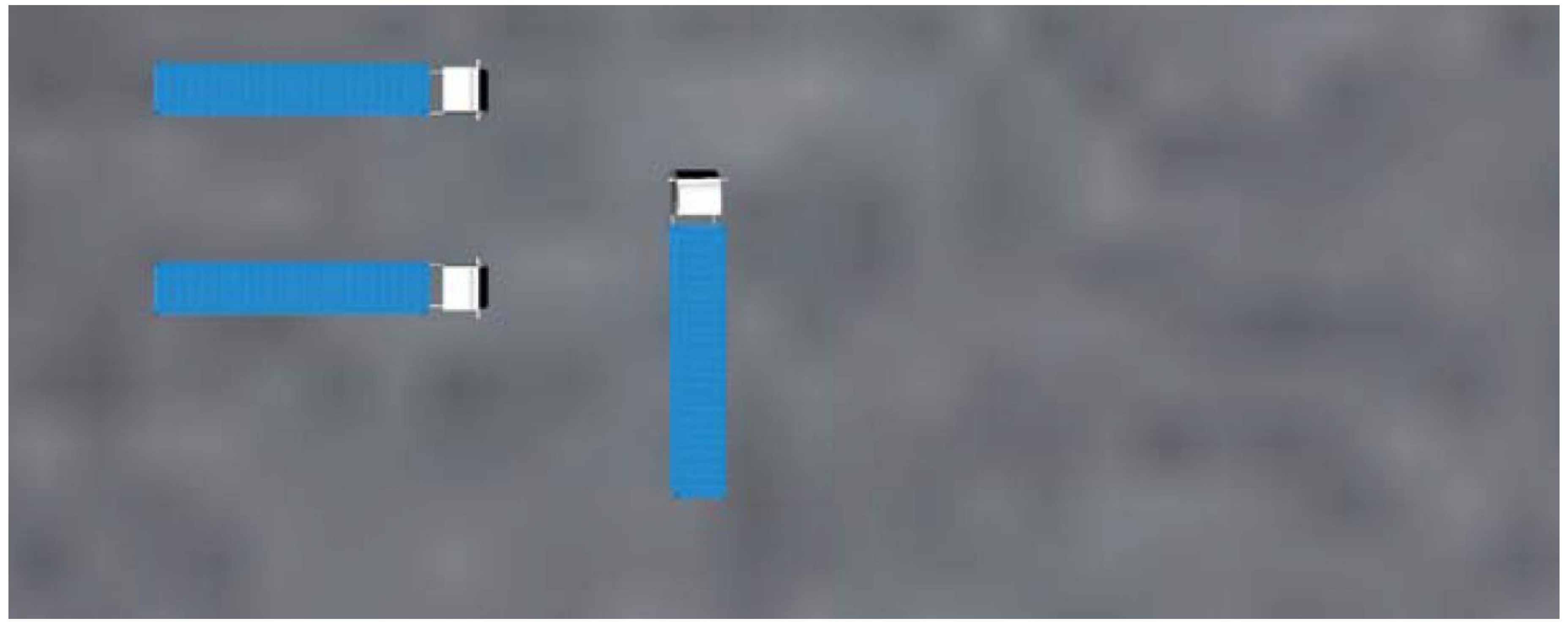
$$J(\mathbf{x}(k), \mathbf{u}(k)) = J_y(\mathbf{x}(k)) + J_u(\mathbf{u}(k)) + J_{\Delta u}(\mathbf{u}(k))$$

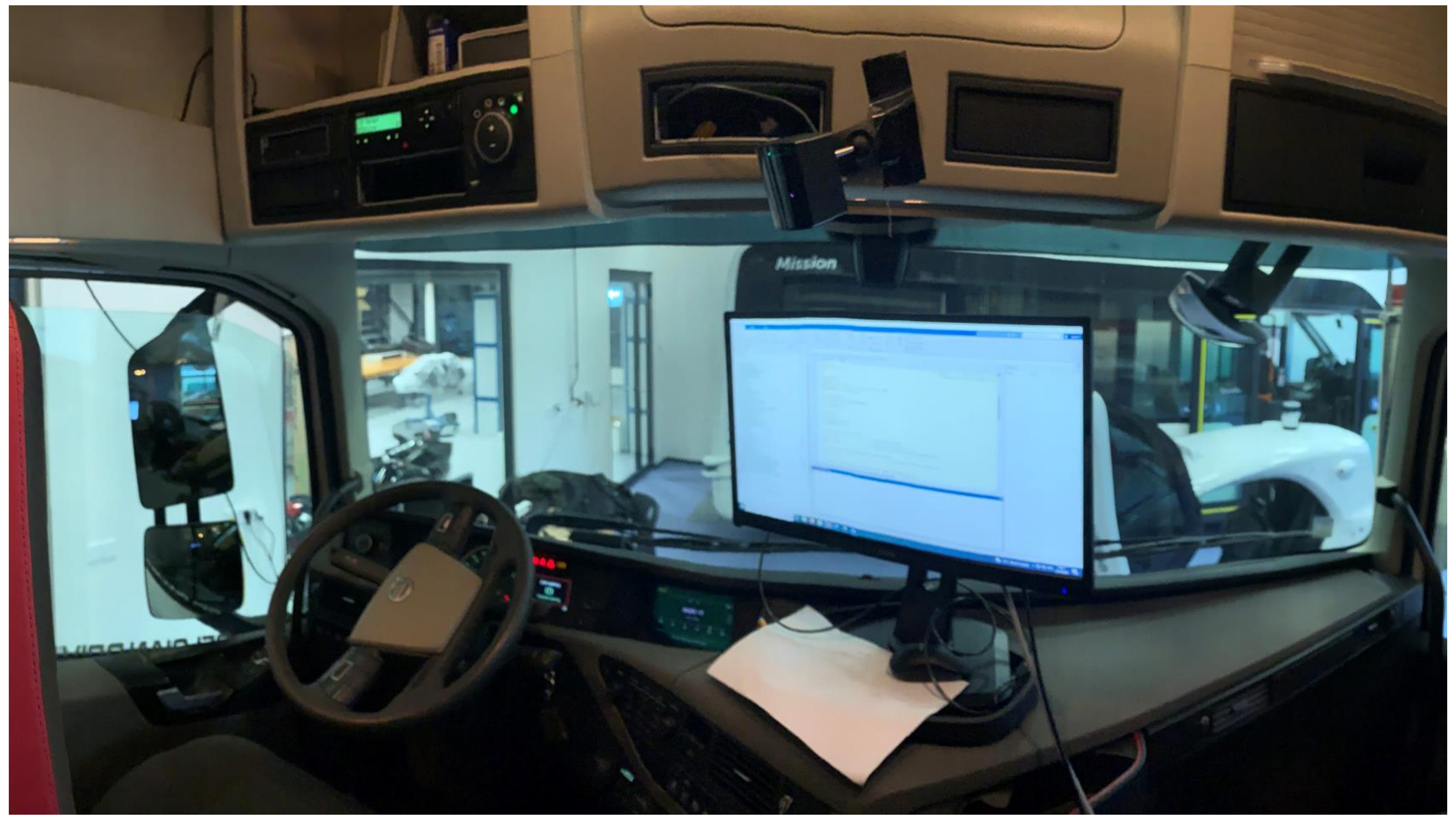
*Model Predictive Control-based Driver Assistance System | TU Delft Repositories

AVEC'22

Controller Implementation and Verification

- Model in the Loop (Without driver interaction) – Matlab environment
- Hardware in the loop – Experimental testing
- Human in the loop - Virtual Reality Simulator

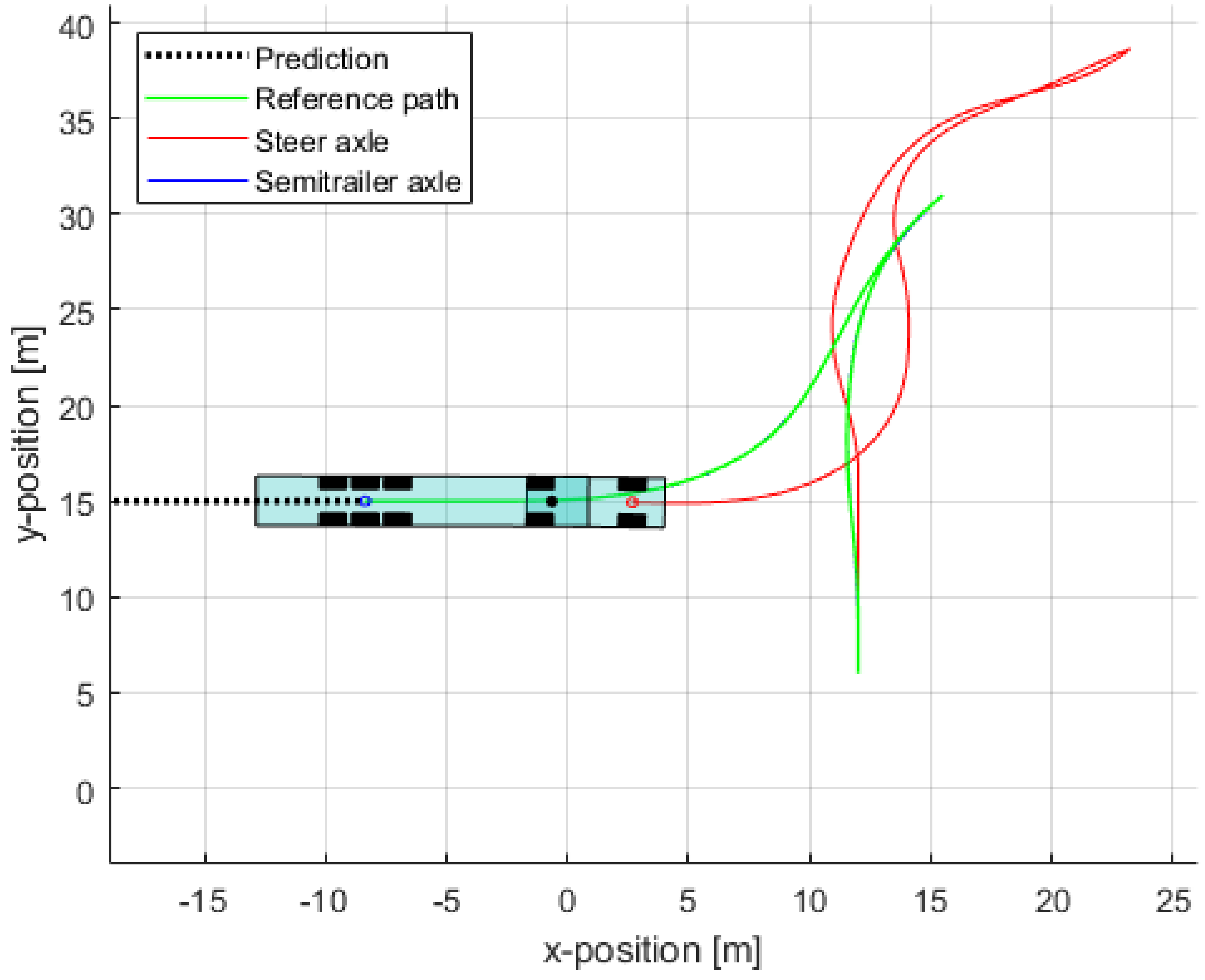


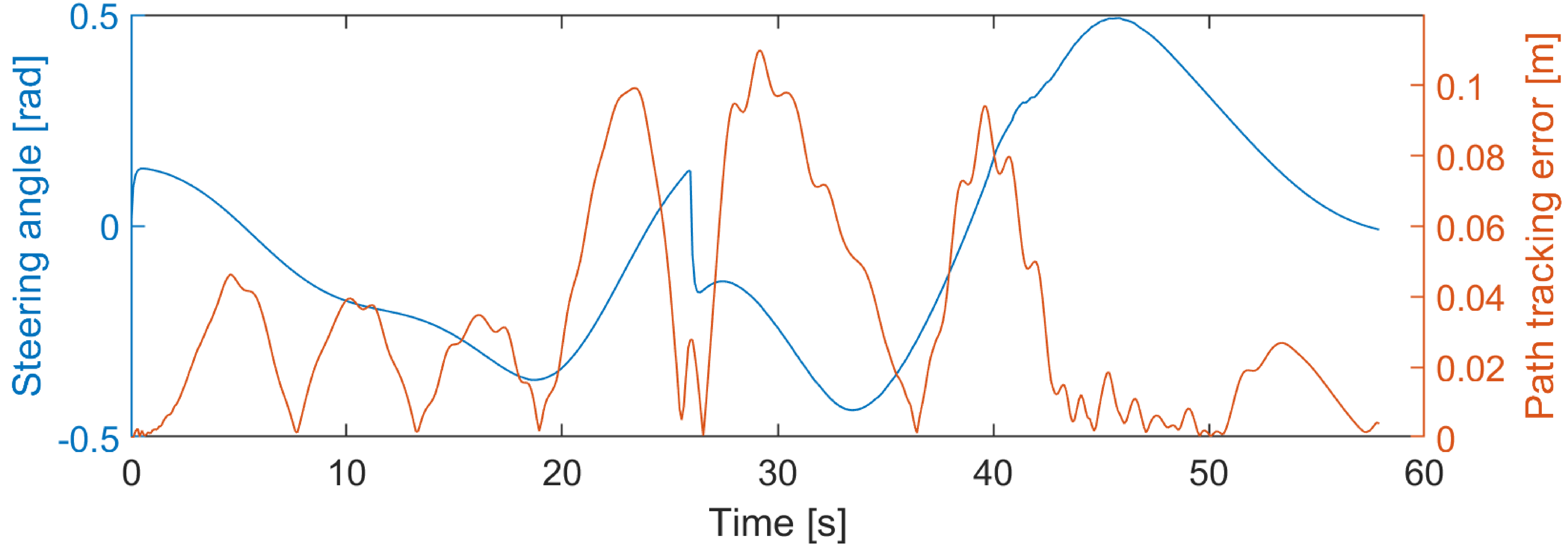


HAN_UNIVERSITY
OF APPLIED SCIENCES

Model in the Loop

- Driver is assumed as perfect actuator (i.e. no delays or disturbances)
- Vehicle behaviour and its model representation in MPC framework is consistent





Hardware in the Loop (Scaled vehicle platform)

- Verification of robustness
- Vehicle combination experiences tyre slip
- Unequal load distribution (combination weight 290 kg)
- Remotely controllable w.r.t. steering and drive torque
- Localization of each unit by RTK GPS

Hardware in the Loop – Autonomous docking

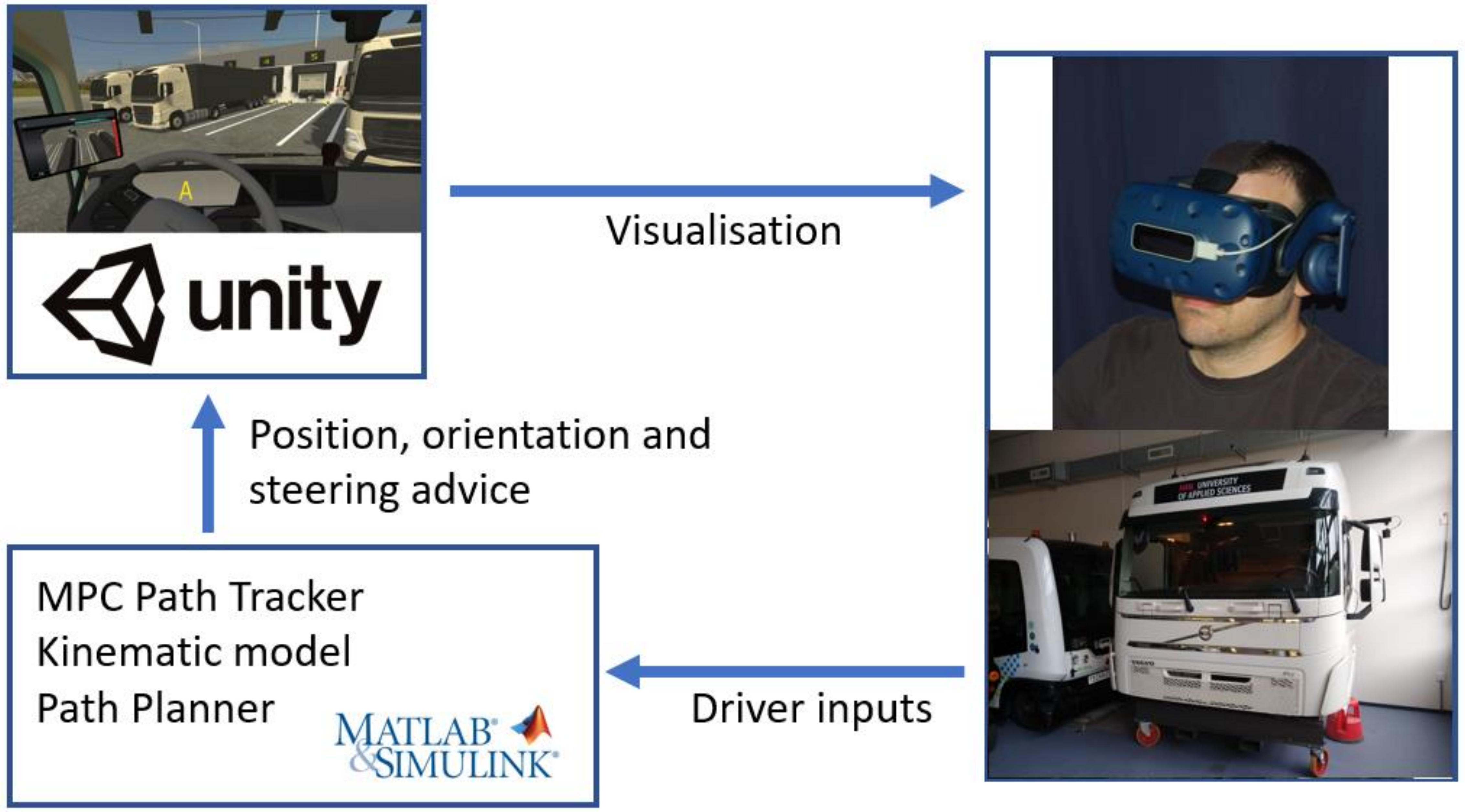
AVEC'22

HAN_UNIVERSITY
OF APPLIED SCIENCES

Human in the Loop @ Virtual Reality Simulator*

AVEC'22

- Verification of robustness with Human drivers in the Loop
- Test various HMI setups
- Examine the drivers acceptance (w.r.t. HMI, reference paths)
- Test failure scenarios

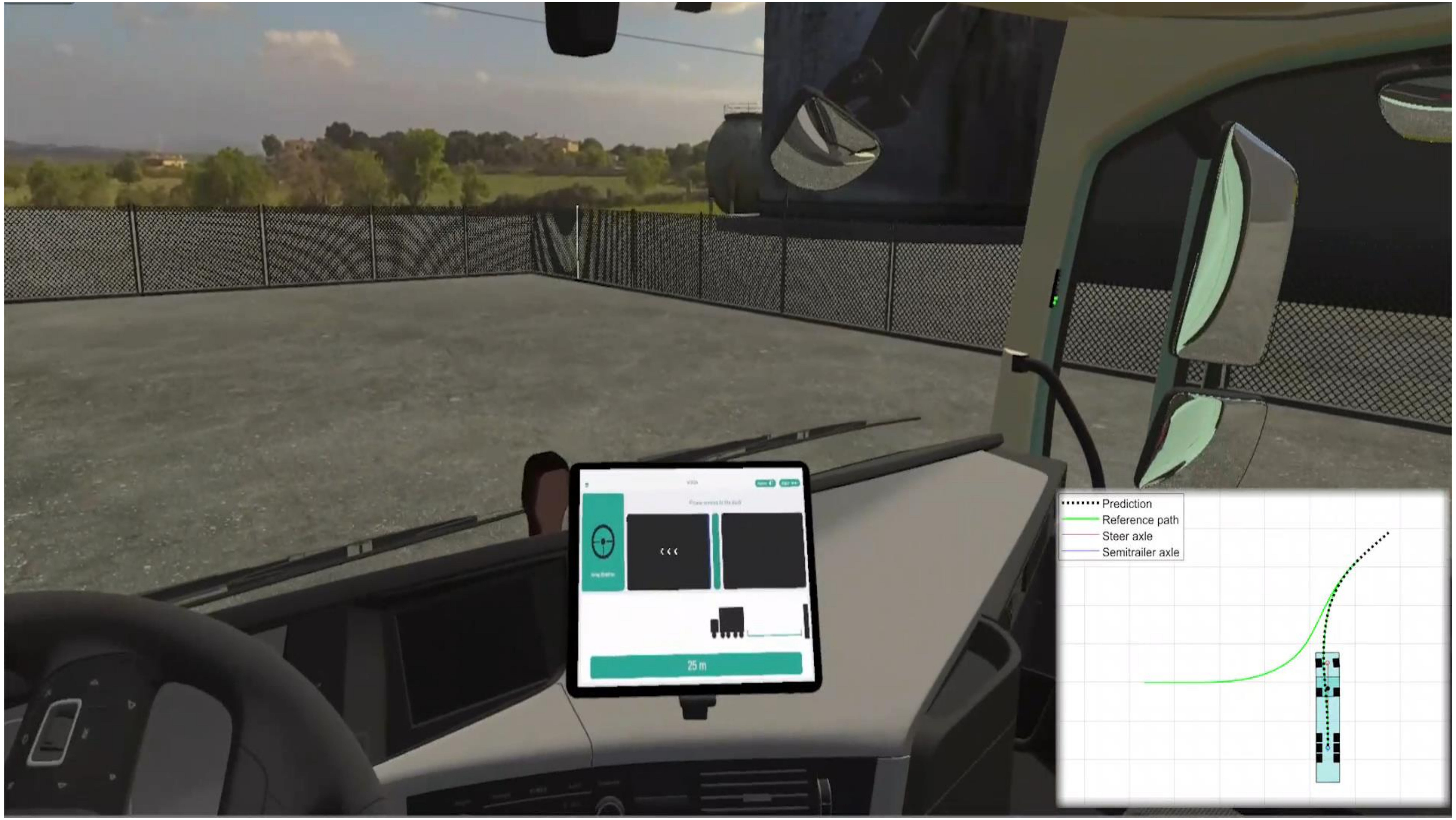


[* Applied Sciences | Free Full-Text | A VR Truck Docking Simulator Platform for Developing Personalized Driver Assistance (mdpi.com)]

HAN_UNIVERSITY OF APPLIED SCIENCES

Virtual Reality Simulator View

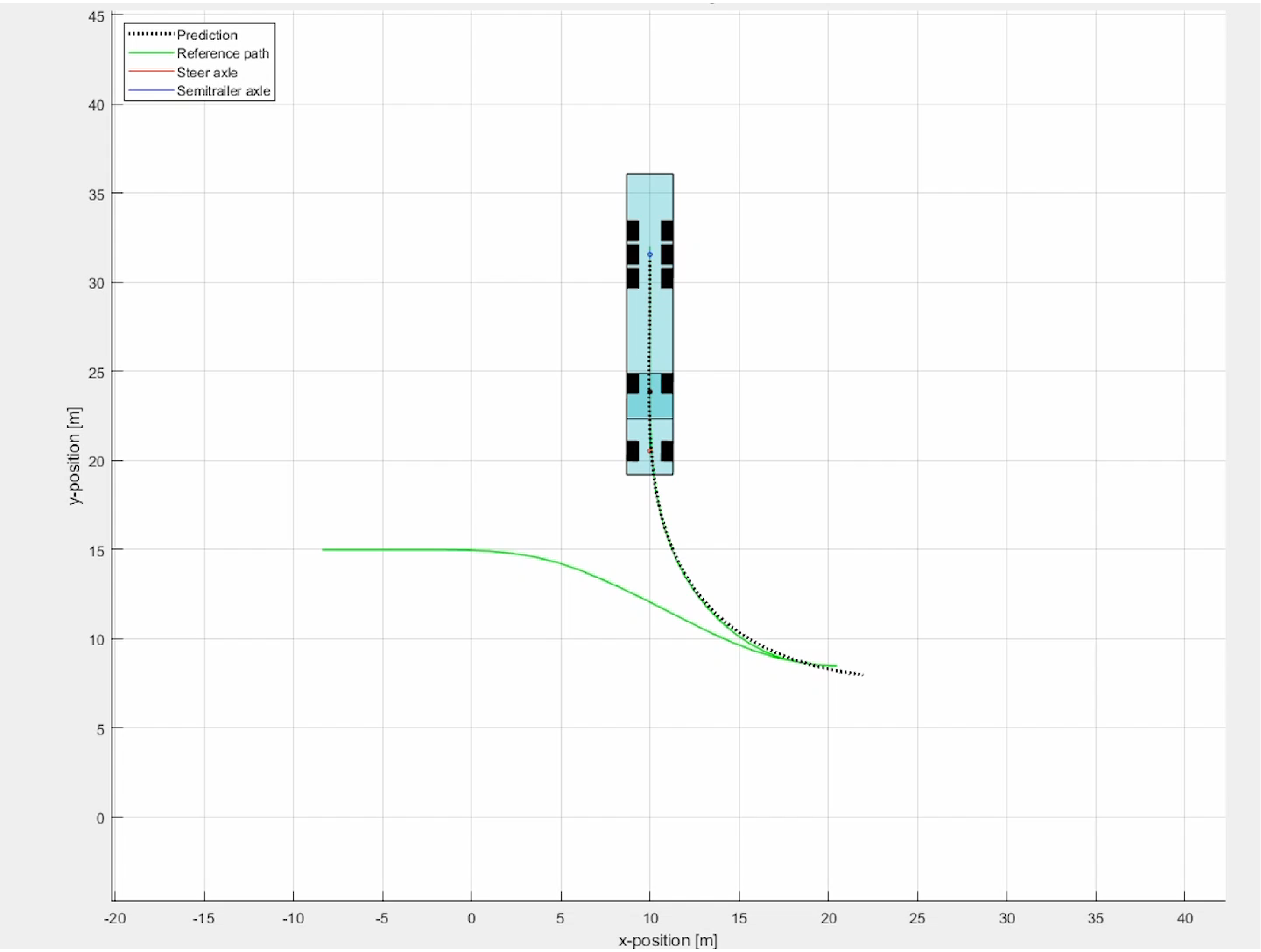
AVEC'22



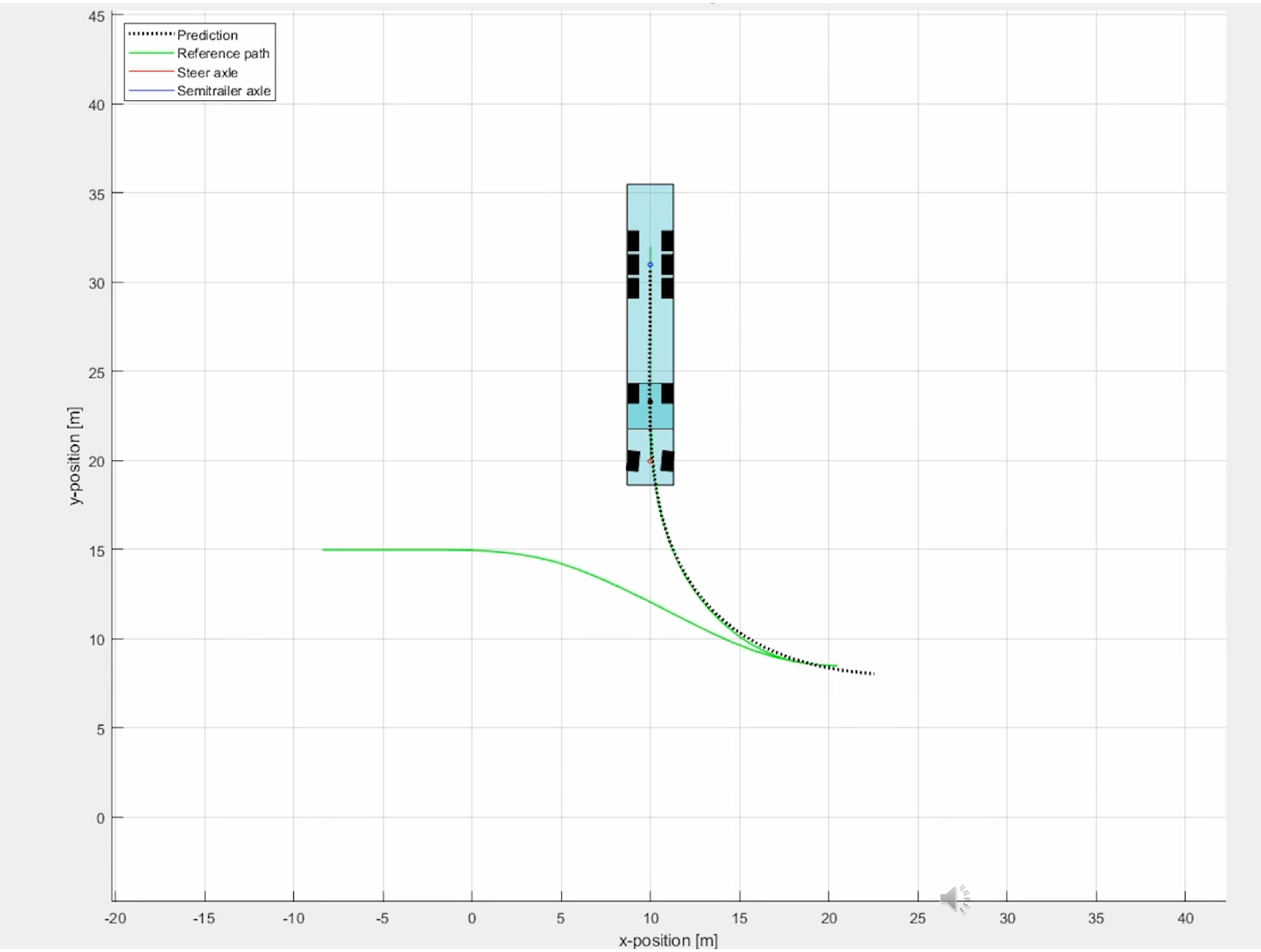
HAN_UNIVERSITY OF APPLIED SCIENCES

AVEC'22

Docking without Assistance



Docking with Assistance



HAN_UNIVERSITY
OF APPLIED SCIENCES

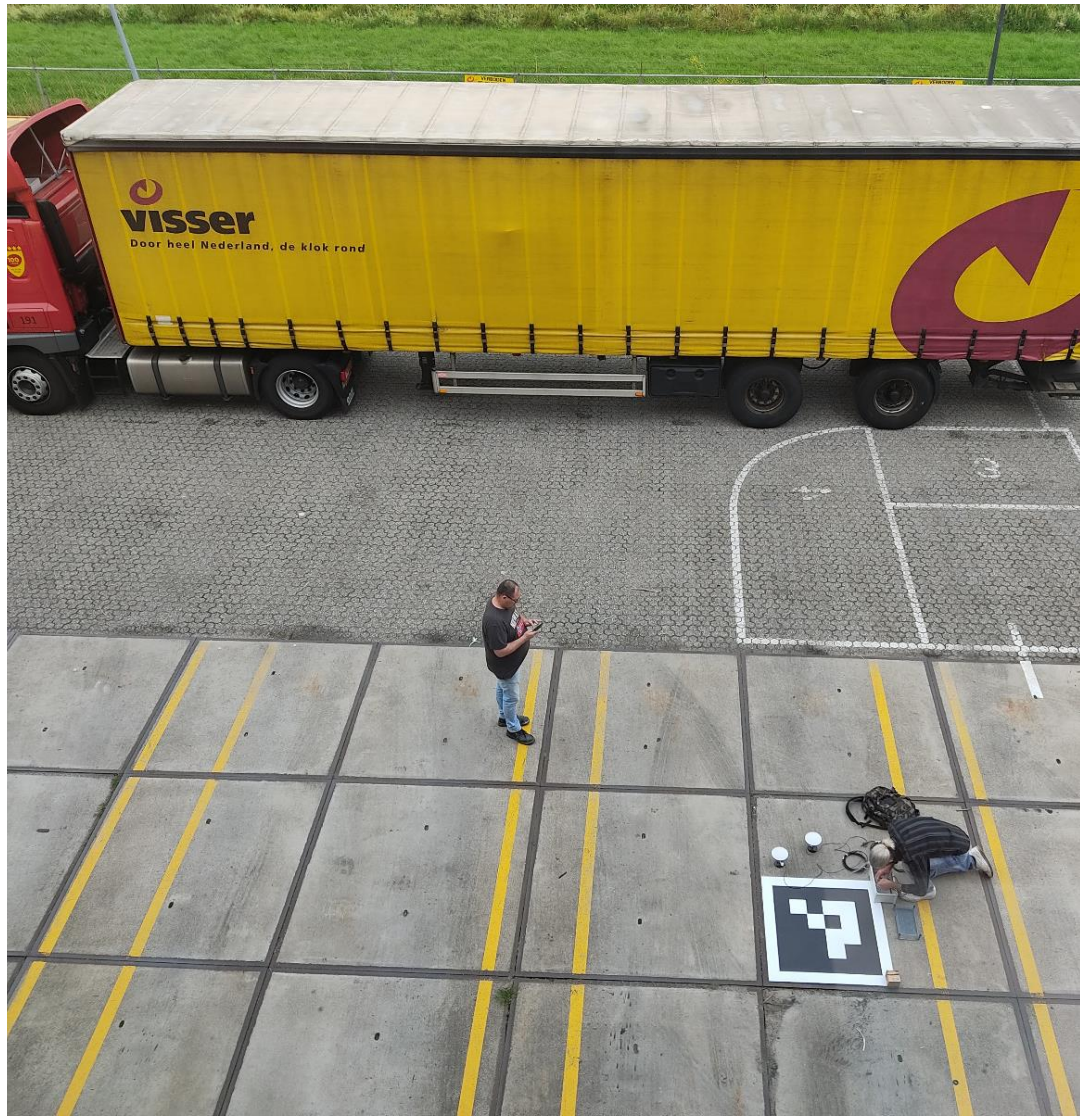
Conclusions

AVEC'22

- MPC-based bidirectional path tracking controller appears as promising solution for both:
  - Automated docking of articulated vehicles
  - Assisted (driver in the loop) docking of articulated vehicles

- The method proves sufficiently robust when deployed into physical scaled demonstrator and even though a considerably simplified model of the vehicle behaviour is used.

- The controller appeared to be more forgiving to driver-introduced steering angle deviations and delays compared to previously developed controllers, i.e. desired steering angle dynamics were perceived as more naturalistic.



Research outlook – installing the entire VISTA framework on pilot site and testing in real life conditions

VISTA

HAN_UNIVERSITY OF APPLIED SCIENCES

Research outlook – MPC-Based Full Scale Autodocking

AVEC'22

THANK YOU

Dr. Karel Kural, MSc, MEng | Senior Researcher | HAN_ University of Applied Sciences |
HAN_ Academy of Engineering and Automotive | Ruitenberglaan 29, 6826 CC Arnhem |
Postbus 2217, 6802 CE Arnhem | E karel.kural@han.nl | www.han.nl |

VISTA

5G BLUEPRINT

The research in this paper is conducted as a part of project VISTA, an Interreg V-A project, co-financed by the European Union via the INTERREG Deutschland-Nederland programme and project 5G Blueprint funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 952189.