Modelling and control of Automatic Guided Vehicles (AGVs) for the transport of meals, laundry and waste in the healthcare domain

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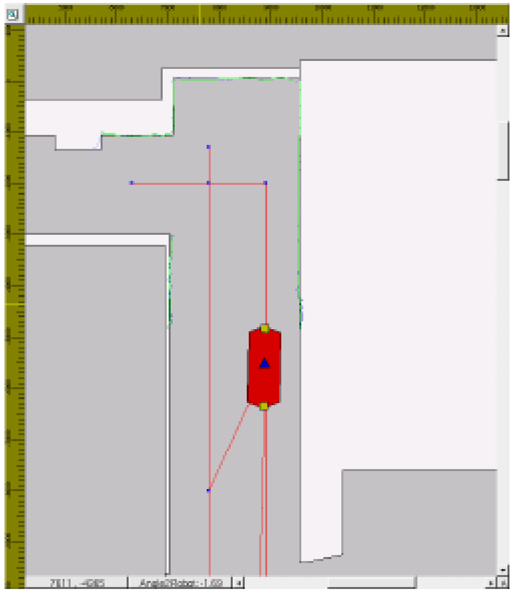
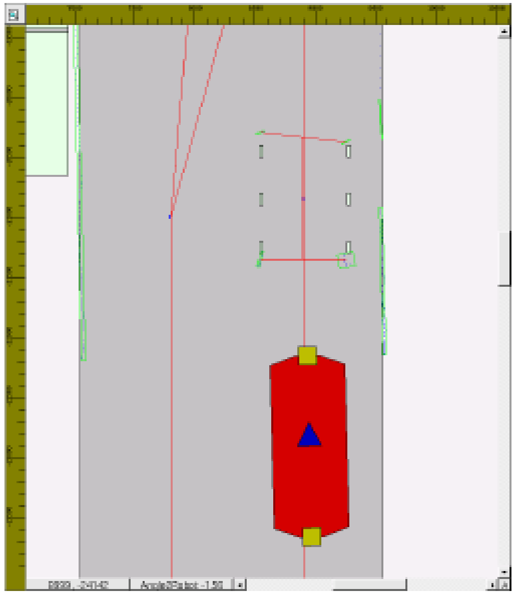
Application of the AGV

- Navigation in large installations
- localization
  - Odometery
  - Matching of 2D laser scanner measurement on predefined maps





- Drive on predefined logical paths
  - constrains (wait for elevator, …)
  - actions (Control strategy, signalize,…)
- Detection and pickup of container for transportation

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Automatic Guided Vehicles

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Steering with mobile robots in general

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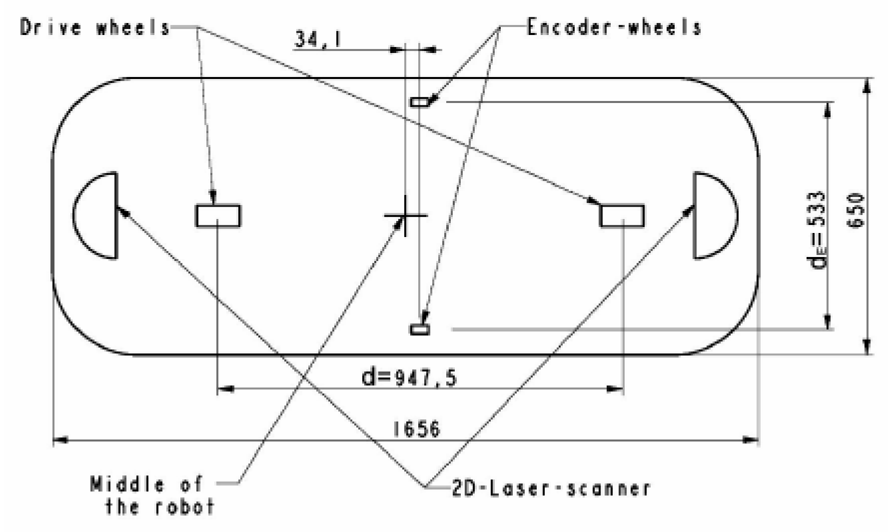
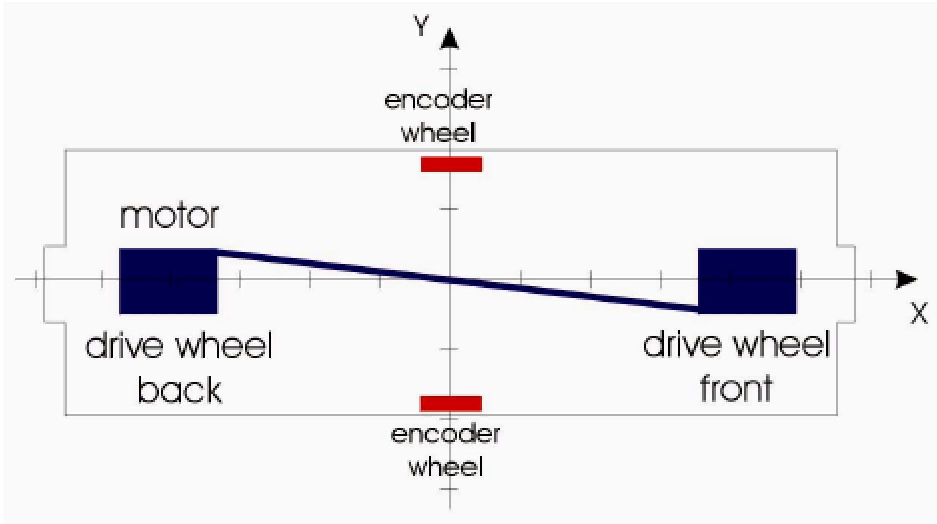
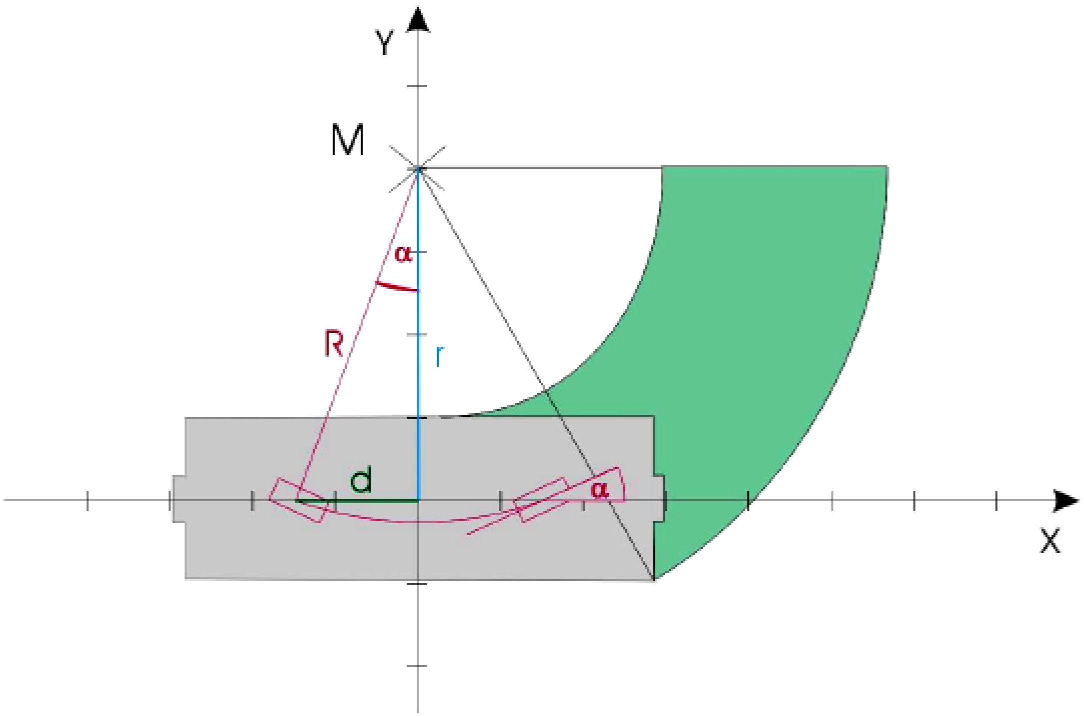
Technical build-up of the Automatic Guided Vehicles





- Length of 1.6 m
- Height of 0.35 m
- Width of 0.75 m
- Weight of 200 kg
- Payload up to 400 kg

Steering with AGV



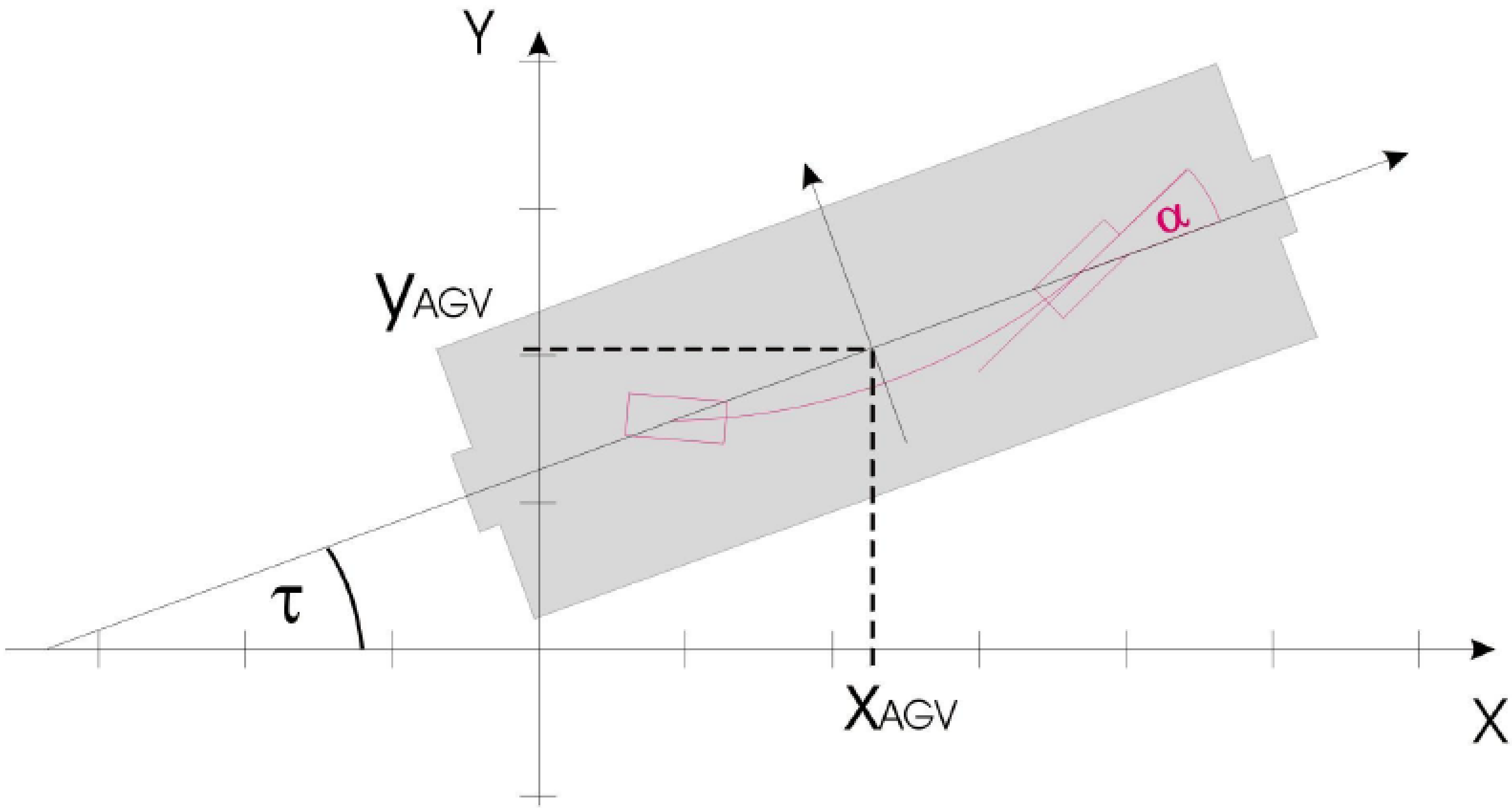
Can be controlled:

- Speed of the driving wheel v_{DW}
- steering angle α

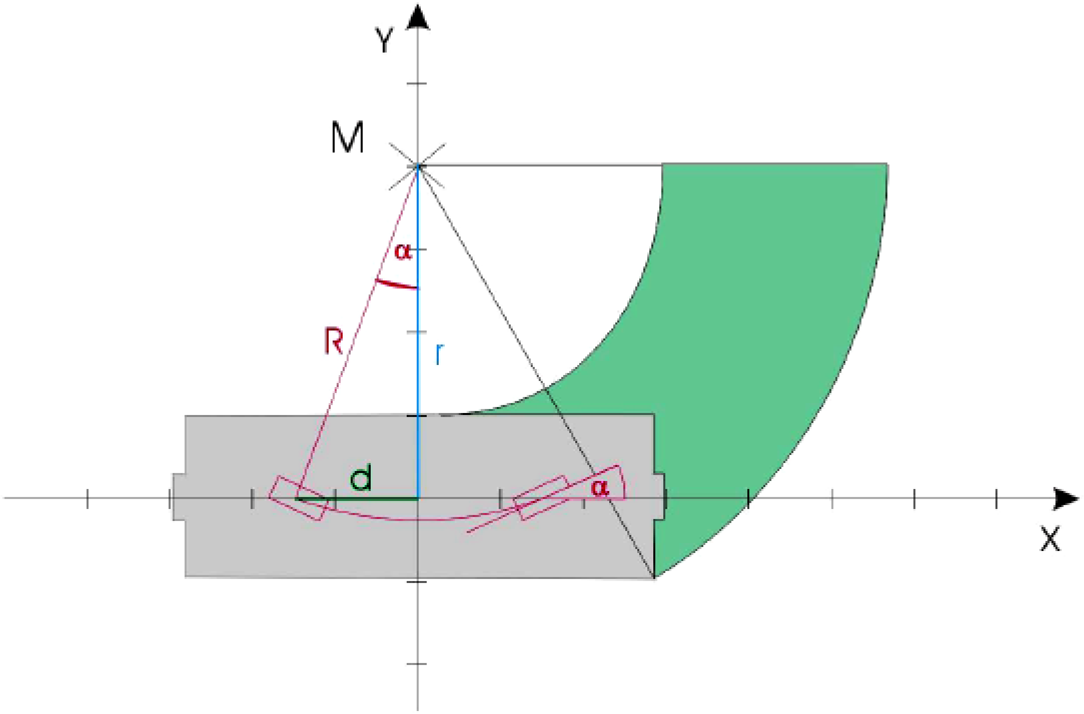
Should be controlled:

- Position of the AGV
- Orientation τ
- Speed of the AGV v_{AGV}

Kinematic model of the AGV



Correlation between Steering angle and steering curve



$$r = \frac{d}{2 \cdot \tan(a)}$$

$$R = \frac{d}{2 \cdot \sin(a)}$$

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Kinematic model of the AGV

Differential equation for the forward motion

$$\dot{x}_{DW} = v_{DW} \cdot \cos(t - a)$$
$$\dot{y}_{DW} = v_{DW} \cdot \sin(t - a)$$

Differential equation for the rotation around the z-axis

$$\dot{t} = 2 \cdot \frac{v_{DW}}{d} \cdot \sin(a)$$

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Kinematic model of the AGV

Relation between driving wheel and AGV center

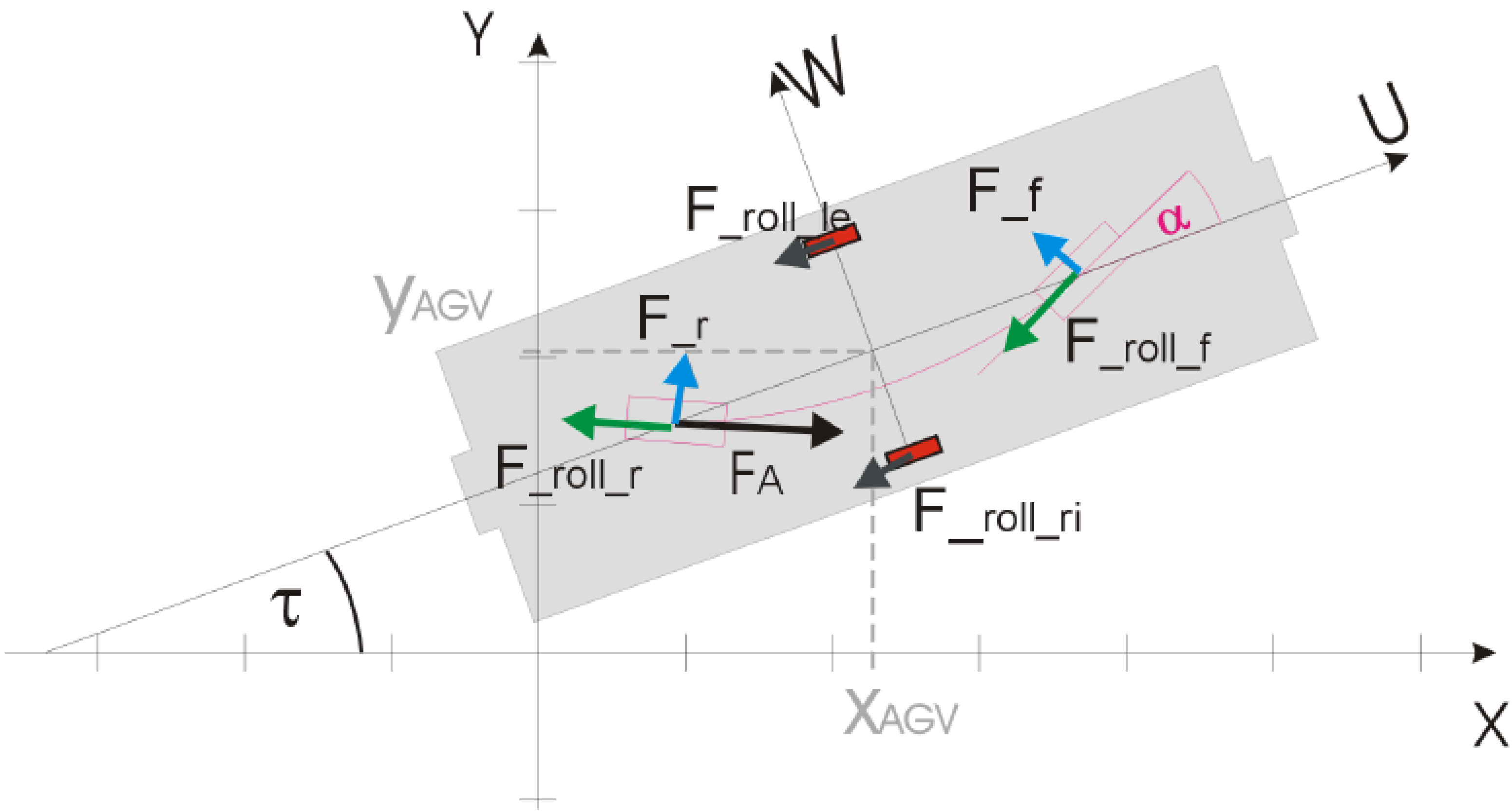
$$x_{AGV} = x_{DW} + \frac{d}{2} \cdot \cos(t)$$

$$y_{AGV} = y_{DW} + \frac{d}{2} \cdot \sin(t)$$

Speed of the AGV in correlation with the driving wheel speed

$$v_{AGV} = v_{DW} \cdot \cos(a)$$

Forces and torques on the AGV



Dynamic model of the AGV

Assumptions:

$$m_{AGV} \cdot \ddot{z} = 0 = \sum F_z = F_{EL-Z} + F_{ER-Z} + F_{DWF-Z} + F_{DWR-Z} - F_G$$

$$F_{EL-Z} = F_G \cdot \frac{d}{2 \cdot (d_E + d)} \qquad F_{DWF-Z} = F_G \cdot \frac{d_E}{2 \cdot (d_E + d)}$$

$$F_{ER-Z} = F_G \cdot \frac{d}{2 \cdot (d_E + d)} \qquad F_{DWR-Z} = F_G \cdot \frac{d_E}{2 \cdot (d_E + d)}$$

rolling

friction

forces

$$\mathrm{F_{roll\_(f/r)}} = \frac{\mu_{\mathrm{roll}}}{\mathrm{r_{DW}}} \cdot \mathrm{F_{DW(F/R)-Z}}$$

$$\mathrm{F_{roll\_(le/ri)}} = \frac{\mu_{\mathrm{roll}}}{\mathrm{r_{EW}}} \cdot \mathrm{F_{EW(L/R)-Z}}$$

Calculation of the side forces on the driving wheels :

$$F_{(f/r)} = K_{(f/r)} \cdot \beta_{(f/r)}$$

$K_{(f/r)}$: stiffness of the wheels

$\beta_{(f/r)}$: slip angle

$$\beta_f = \alpha - \frac{v_W + \frac{d}{2}\cdot\omega}{v_U}, \quad \beta_r = \alpha + \frac{v_W - \frac{d}{2}\cdot\omega}{v_U}$$

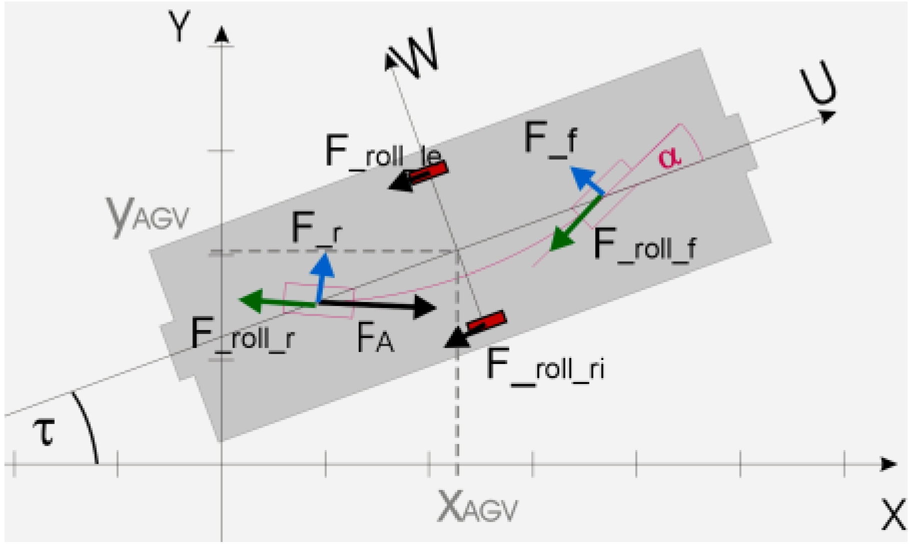
Dynamic model of the AGV

Dynamic equations:

$$m_{AGV} \cdot (\ddot{u} - v_W \cdot \omega) = \sum F_U$$

$$m_{AGV} \cdot (\ddot{w} + v_U \cdot \omega) = \sum F_W$$

$$I_{zAGV} \cdot \ddot{\tau} = \sum M_z$$



$$\sum F_U = F_{A-U} - F_{roll\_f-U} - F_{roll\_r-U} - F_{roll\_le-U} - F_{roll\_le} - F_{roll\_ri} + F_{r-U} - F_{f-U}$$

$$\sum F_W = -F_{A-W} - F_{roll\_f-W} + F_{roll\_r-W} + F_{r-W} + F_{f-W}$$

$$\sum M_z = F_A \cdot l_1 - F_f \cdot l_2 + F_r \cdot l_2 - F_{roll\_r} \cdot l_1 - F_{roll\_f} \cdot l_1 - F_{roll\_ri} \cdot \frac{d_E}{2} + F_{roll\_le} \cdot \frac{d_E}{2}$$

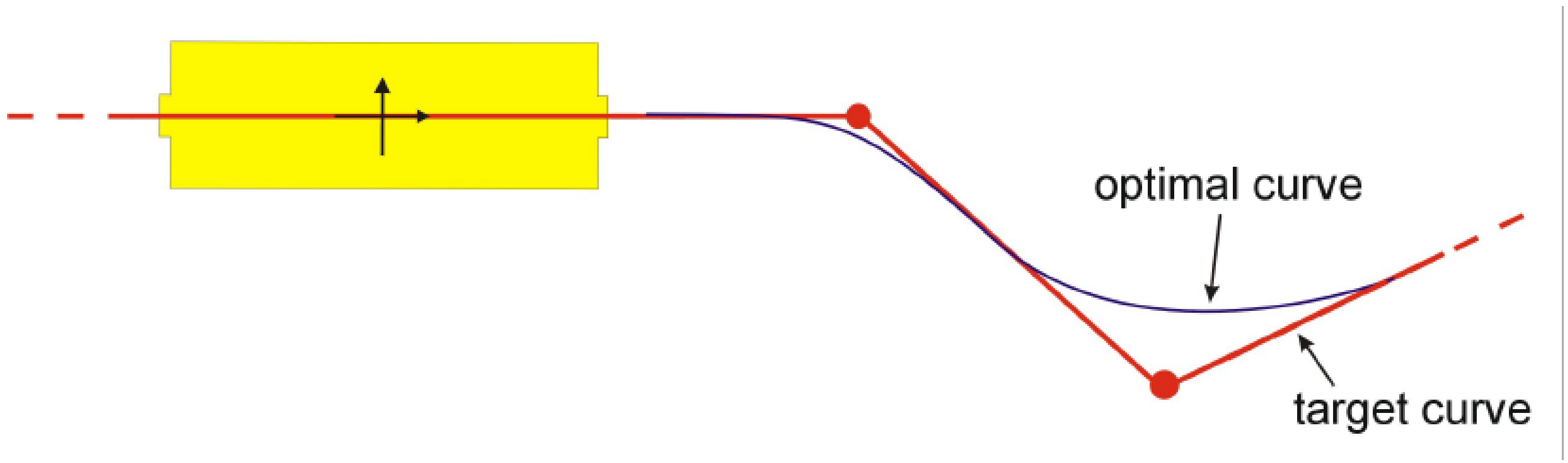
with: $l_1 = \frac{d}{2} \cdot \sin(a), l_2 = \frac{d}{2} \cdot \cos(a)$ and for example $F_{A-U} = F_A \cdot \cos(a), F_{A-W} = F_A \cdot \sin(a)$

Control problems

- high accuracy of the steering necessary
- processing time of the algorithm should be low
- controller should not produces mechanical load and high stress of the drive wheels
- no consideration of the payload possible

Actual steering controller

- Driving on predefined paths
- Finding the optimal steering curve



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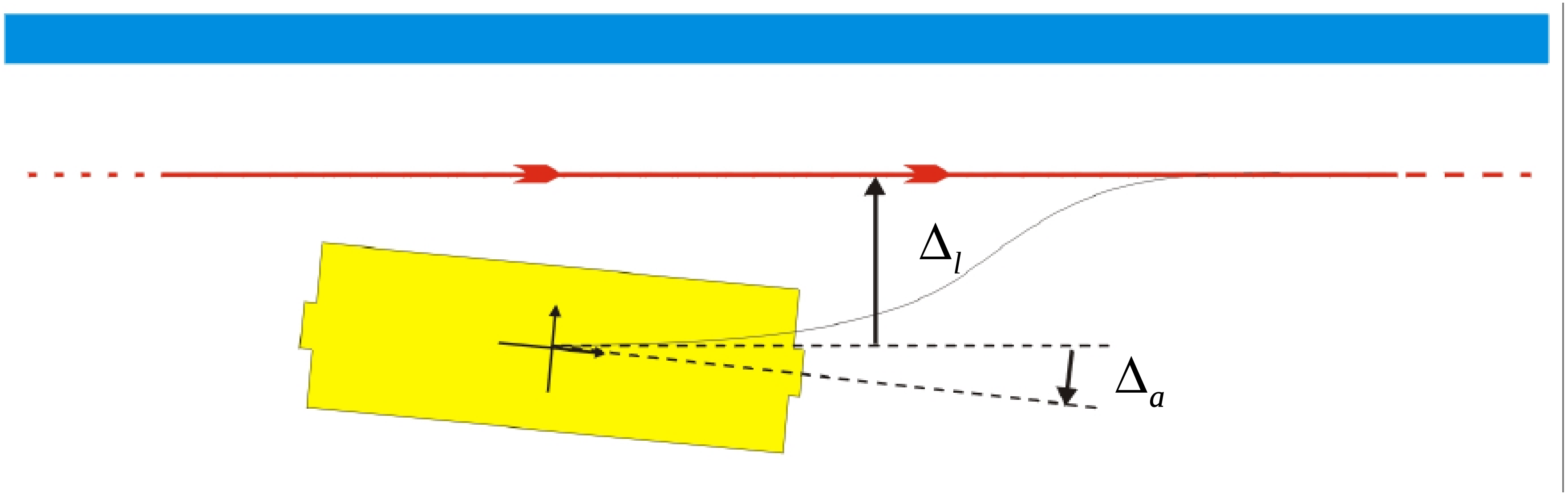
Actual control: driving on predefined paths



Control law:

$$a_s = \frac{d_a \cdot \Delta_a + d_l \cdot \Delta_l}{d_v \cdot (v + v_{min})}$$

a_s :steering angle

d_a :angleparameter

d_l :distance parameter

d_v : velocity parameter

Δ_a : angle error

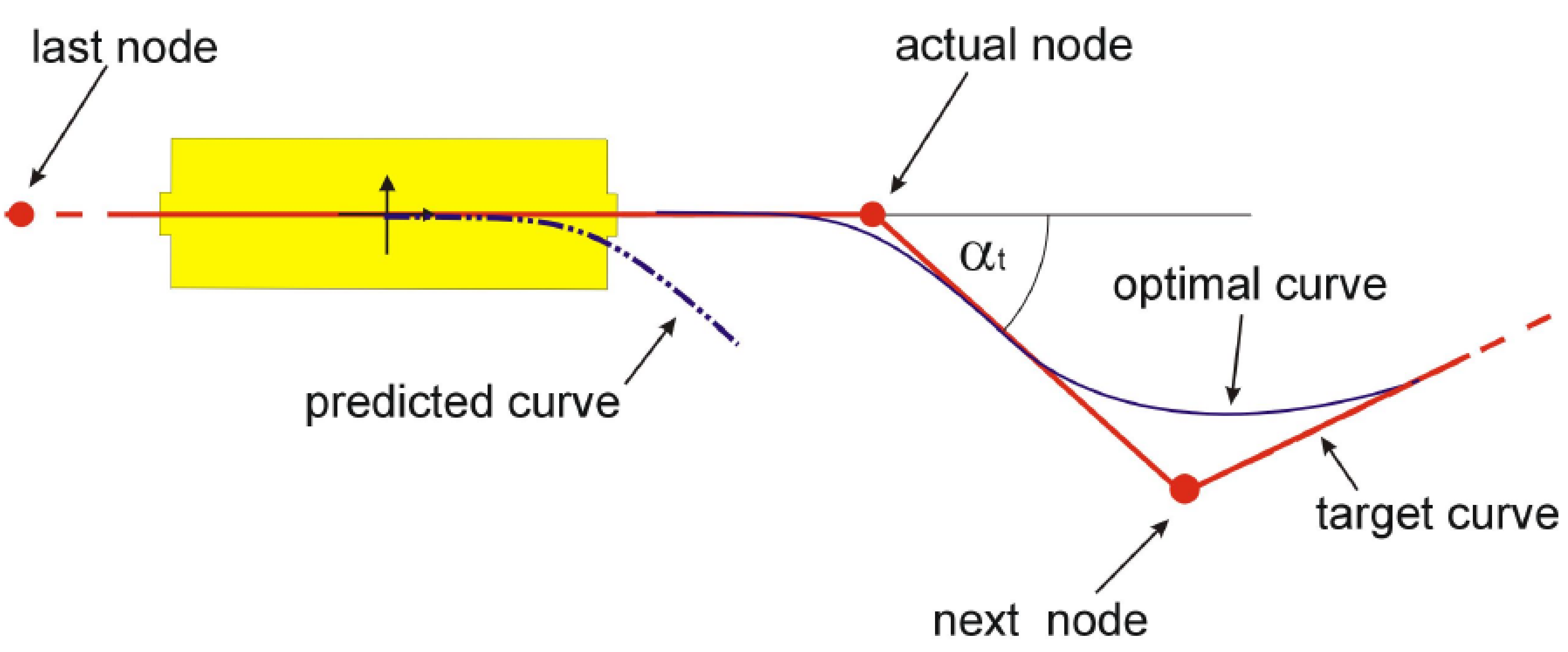
Δ_l : distance error

v : actual velocity

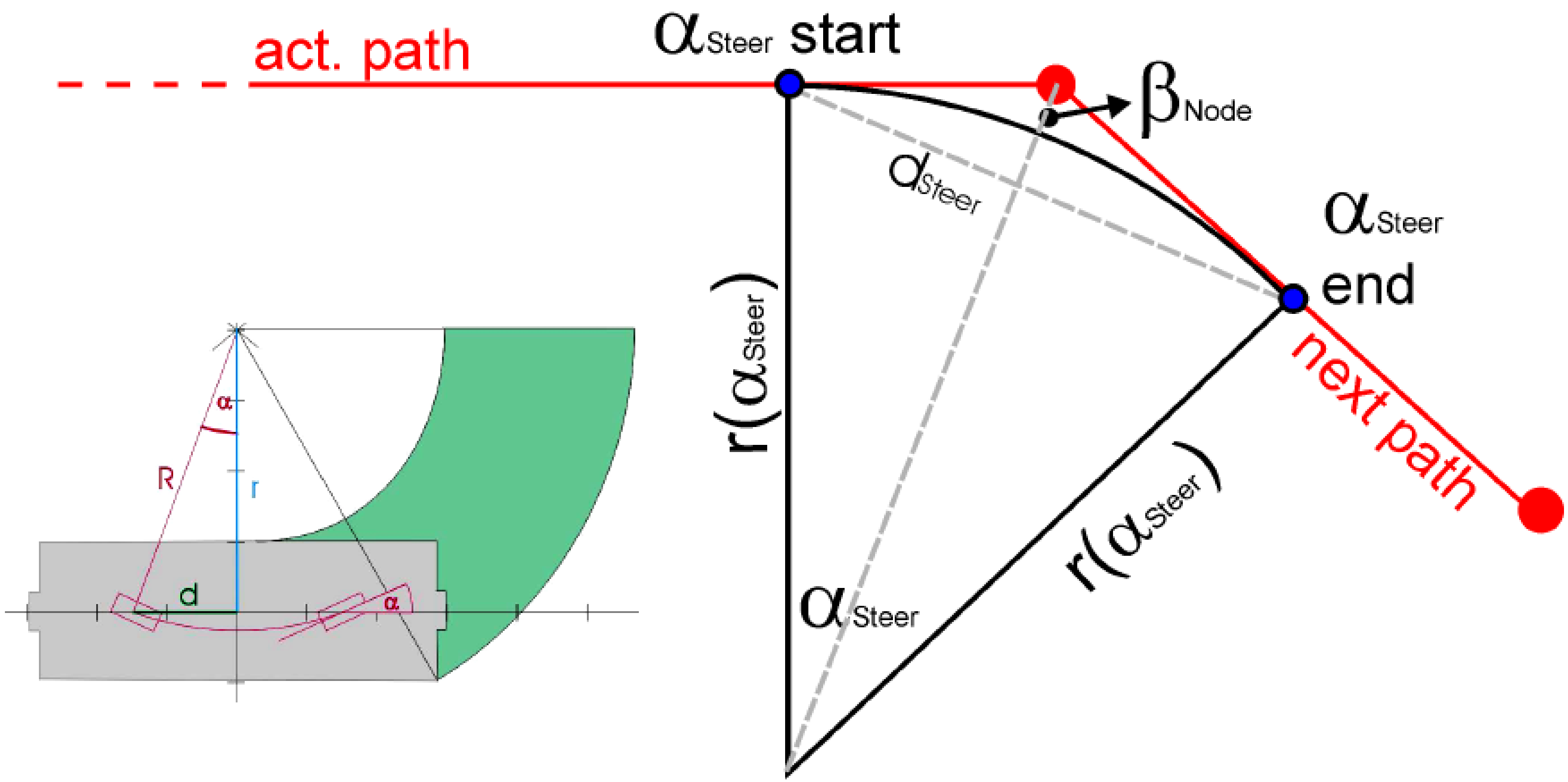
v_{min} : min. velocity

Actual control: steering prediction

Finding the optimal steering curve



Actual Control: steering prediction



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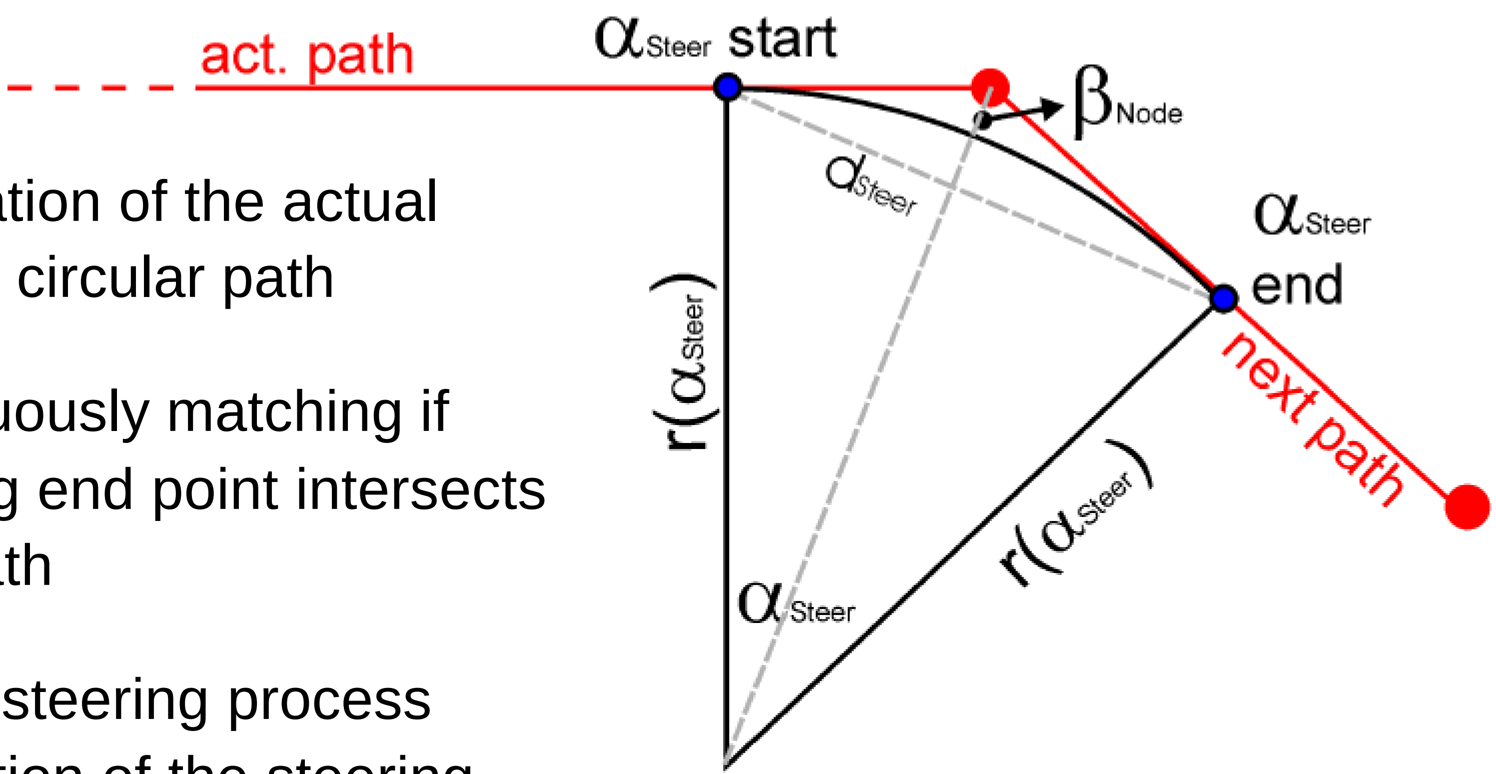
Actual Control: steering prediction



- Calculation of the actual optimal circular path
- Continuously matching if steering end point intersects next path
- During steering process adaptation of the steering angle

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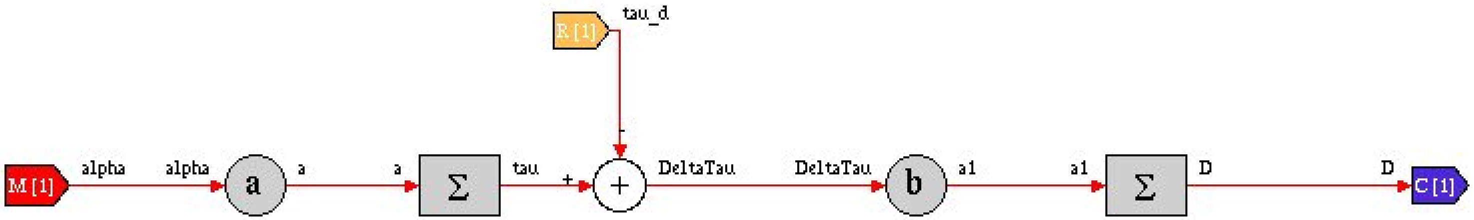
EICAS control: simplified model

τ AGV orientation

D Distance between AGV and reference line

$$\begin{cases} t(i+1) = t(i) + Ts \cdot \dfrac{2v}{d} \cdot tga \\ D(i+1) = D(i) + Ts \cdot v \cdot \sin(t - t_{ref}) \end{cases}$$



EICAS control: reference generator

Command	steering angle α
Control	Orientation τ
	Distance from desired trajectory

Staright line: open loop commmand $\alpha_o = 0$

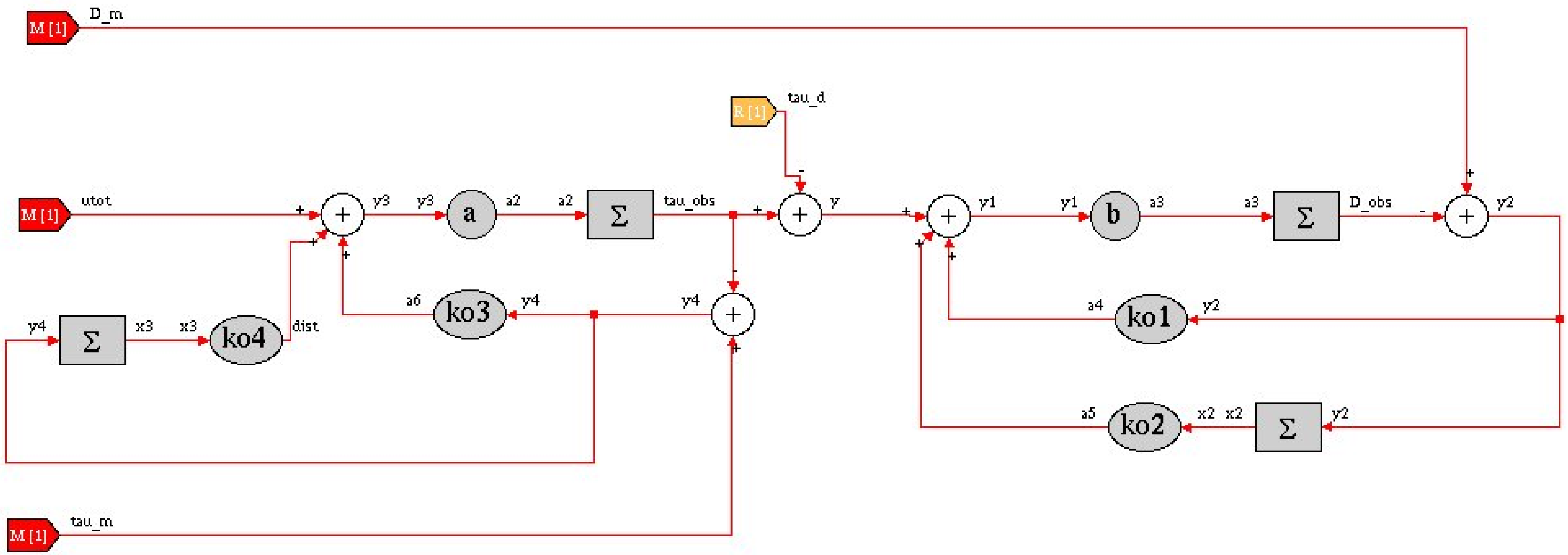
$\tau_{ref} = \tau_{line}$ $D_{ref} = 0$

Curve: predefined optimal path (Considering acc_{α_max} vel_{α_max} α_{steer})

Computation of the beginning point of the curve

EICAS control: the observer

- Observer structure



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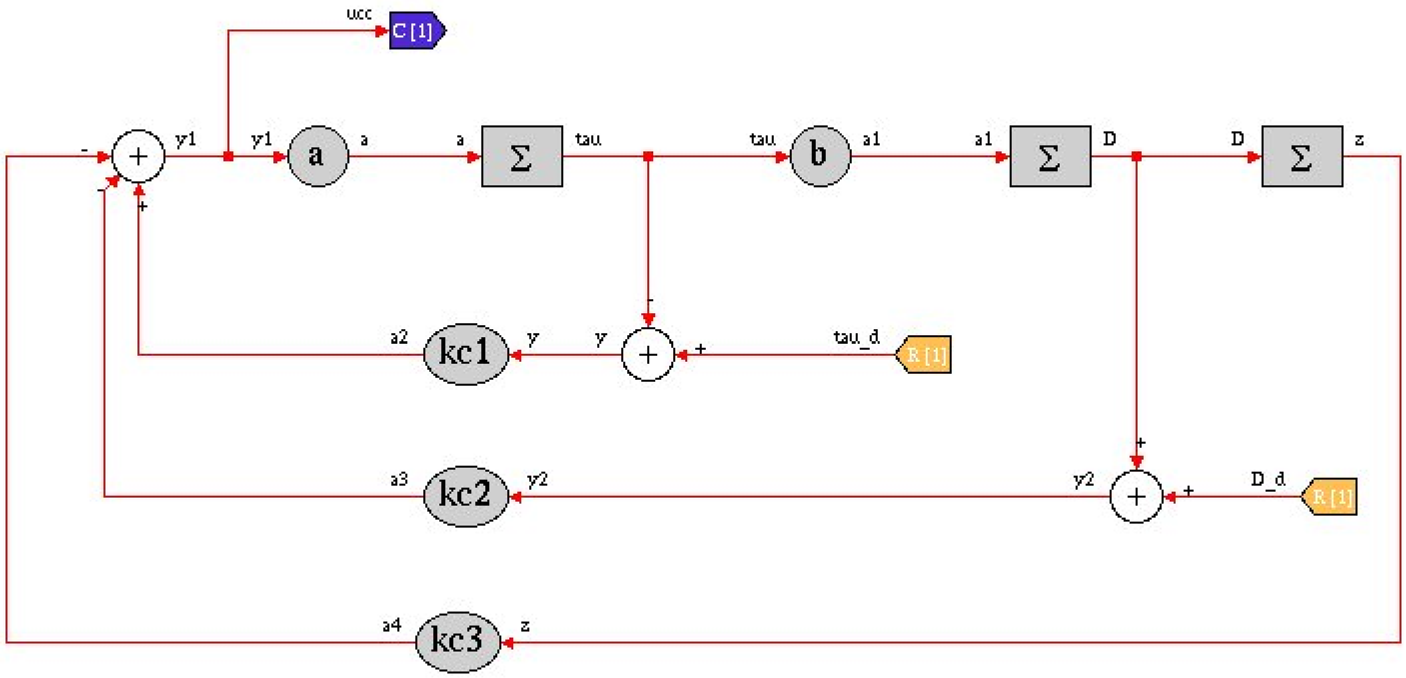
EICAS control: the control

- Control structure



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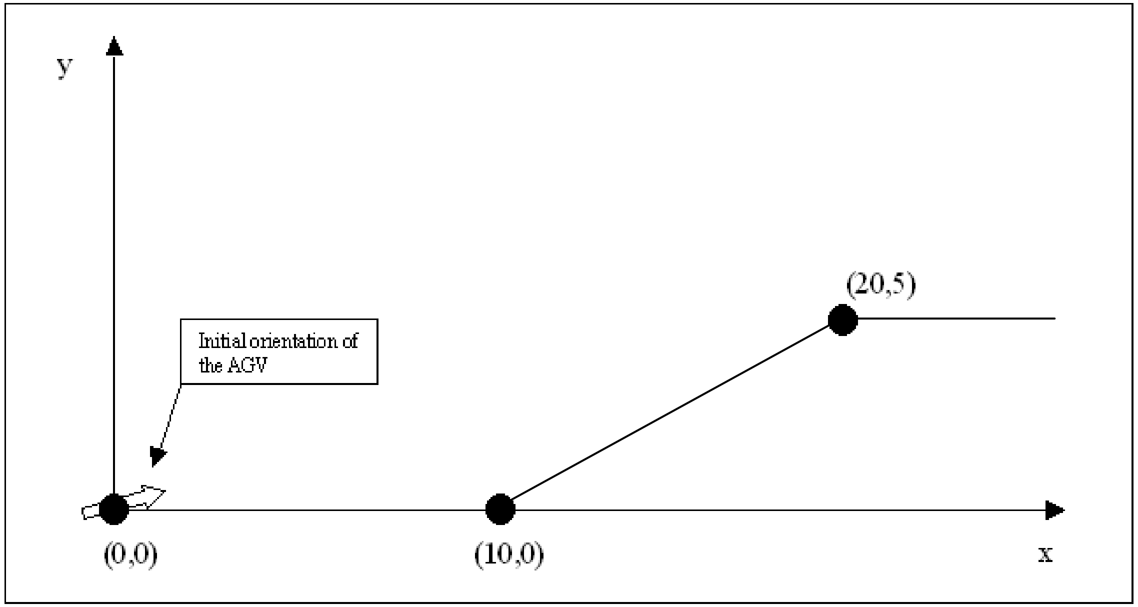
EICAS control: simulation results (1)

- Scenario



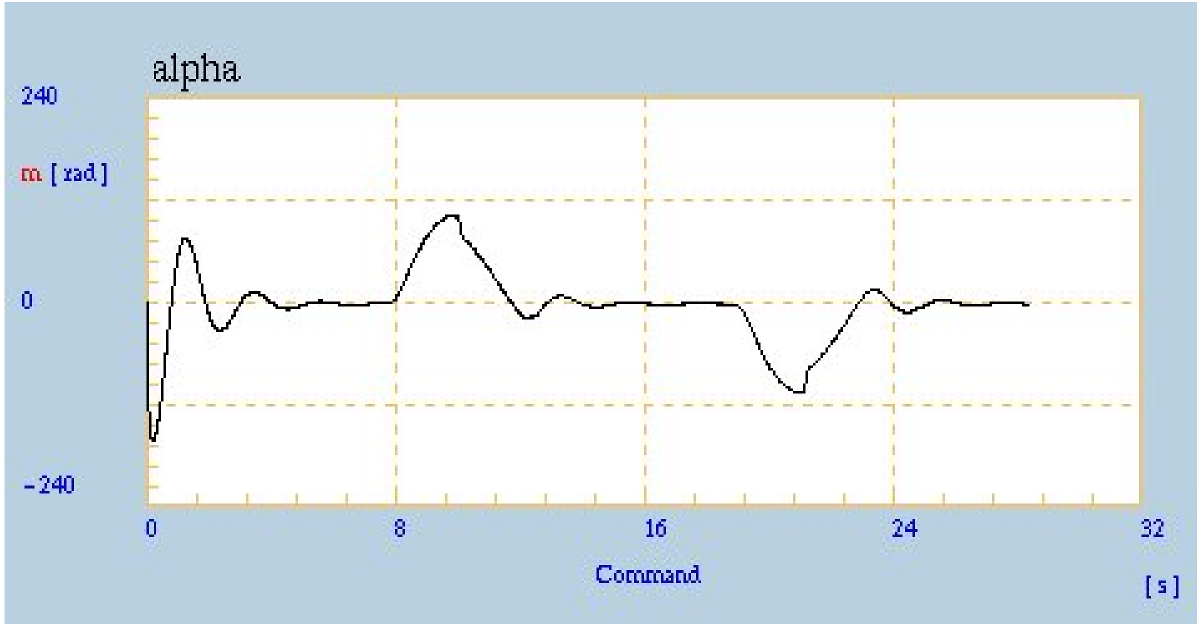
Three lines, strating with $\tau = 0.$ rad

EICAS control: simulation results (2)

- AGV path

EICAS control: simulation results (3)

- Command



Conclusion and outlook

- Dynamic modeling of the AGV-behavior
- Control fits the strang requirements for the AGV
- Improvement of the steering controller by the use of EICASLAB
- Improvement of the driving behaviour
- less mechanical load and stress on the driving wheel