Controller Design and Tuning

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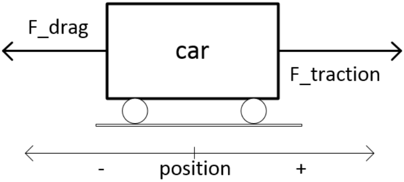
- Our example (closed loop): velocity control in rail car

Moving Car (the physical "plant") Model

$$F_{res} = F_{traction} + F_{drag}$$

$$F_{drag} = -\frac{1}{2} \cdot p \cdot v^2 \cdot C_D \cdot A$$

$$F_{res} = M \cdot a = M \cdot \frac{dv}{dt}$$



$$\frac{dv}{dt} = \frac{1}{M}\left(F_{traction} - \frac{1}{2} \cdot p \cdot v^2 \cdot C_D \cdot A\right)$$

$$v(0) = 0$$

PID Controller

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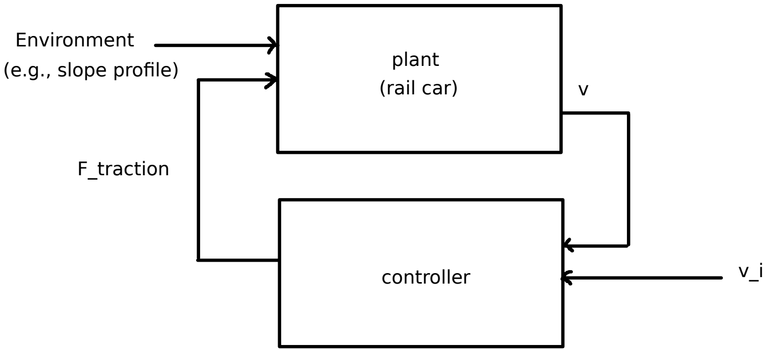
A PID controller produces a control output:

$$K_p \cdot (v_i - v) + K_i \cdot \int (v_i - v)dt + K_d \cdot \frac{d(v_i - v)}{dt}$$

Closed-Loop PID Controller for Velocity Control



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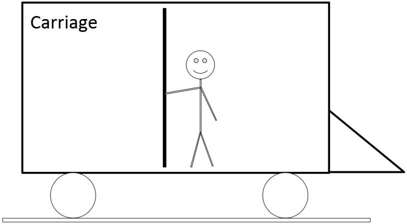

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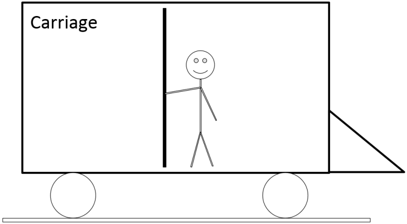

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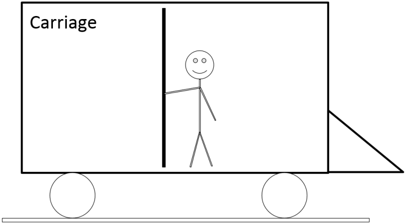

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- The controller determines the acceleration of the train, in an attempt to match (i.e., deviate as little as possible from) a predefined profile of desired velocities.

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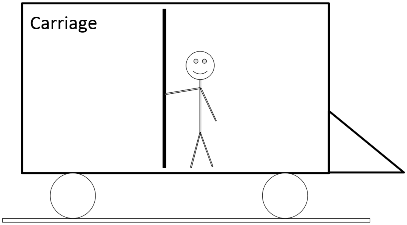

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  The desired (piecewise constant) velocity profile is known beforehand by a central coordinator (and is encoded in a file).

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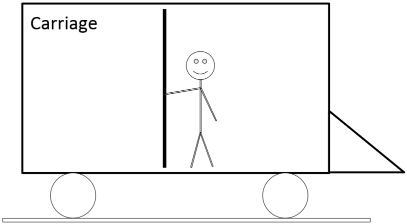

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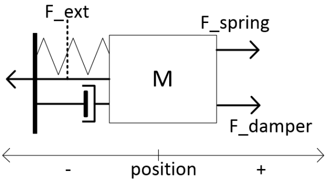
- Passengers should not fall (*i.e.*, accelerate too much).
- Other requirements such as minimizing total energy consumption could be added.

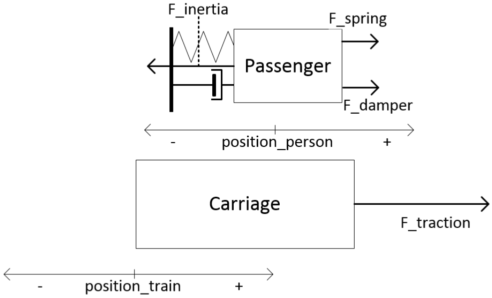
Abstracting the Passenger: Mass-Spring-Damper System

$$
\begin{cases}
F_{ext} &= -f \\
F_{spring} &= -k(-x) \\
F_{damper} &= -c(-v) \\
M \cdot a &= F_{ext} + F_{spring} + F_{damper} \\
\frac{dv}{dt} &= a \\
\frac{dx}{dt} &= v
\end{cases}
$$



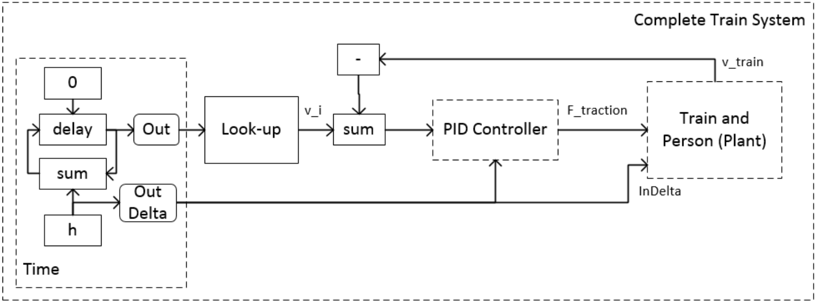
$$
\begin{cases}
\frac{dv}{dt} &= \frac{1}{M}(-f + k \cdot x + c \cdot v) \\
\frac{dx}{dt} &= v
\end{cases}
$$

Abstracting Train-and-Passenger ("Plant" model)



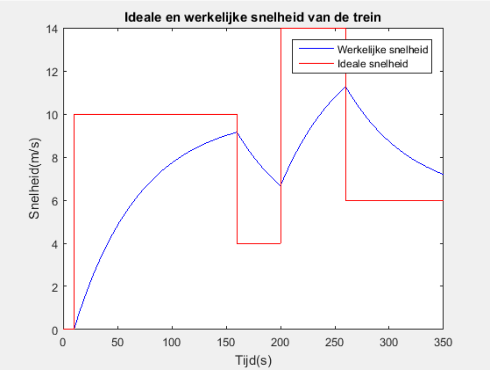
$$
\begin{cases}
m_{passger} * a_{passger} & = k(-x_{passger}) + c(-v_{passger}) - m_{passger} * a_{train} \\
F_{traction} & = (m_{train} + m_{passger}) * a_{train} \\
a_{passger} & = \frac{dv_{passger}}{dt} \\
v_{passger} & = \frac{dx_{passger}}{dt} \\
a_{train} & = \frac{dv_{train}}{dt} \\
v_{train} & = \frac{dx_{train}}{dt}
\end{cases}
$$

Complete System Overview

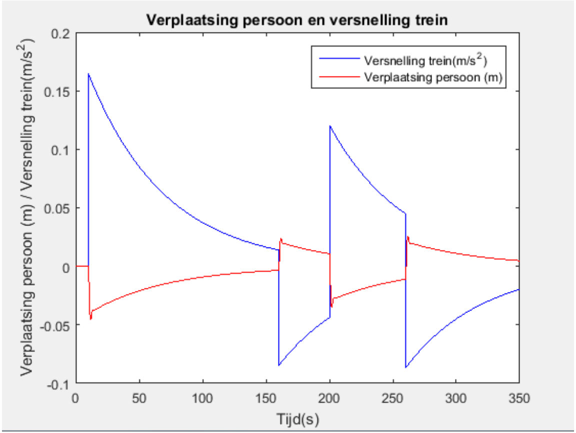


Some Results - Train Velocity

$$\begin{cases} m_{passger} & = 73kg \\ m_{train} & = 6000kg \\ k & = 300 \\ c & = 150 \\ K_p & = 100 \\ K_i & = 0 \\ K_d & = 0 \end{cases}$$



Some Results - Passenger Displacement and Acceleration



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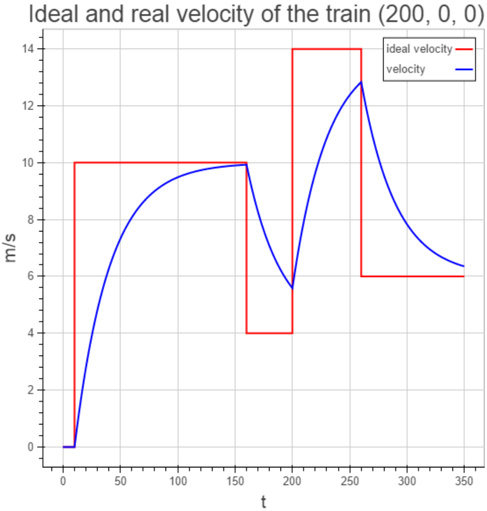

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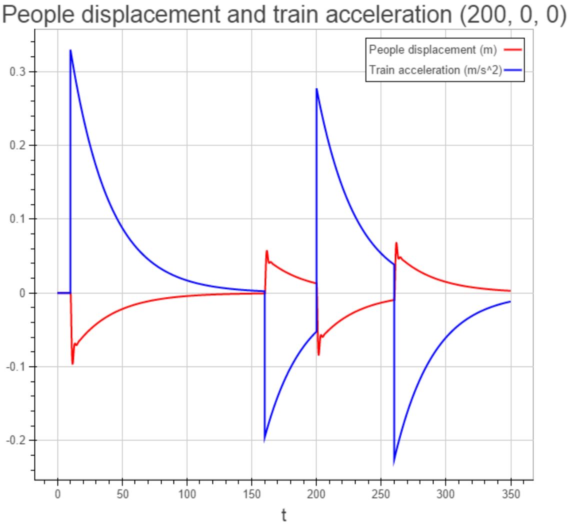

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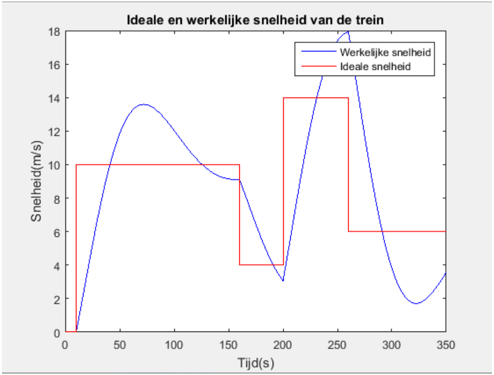
$$\begin{cases} m_{passger} & = 73kg \\ m_{train} & = 6000kg \\ k & = 300 \\ c & = 150 \\ K_p & = 200 \\ K_i & = 10 \\ K_d & = 0 \end{cases}$$



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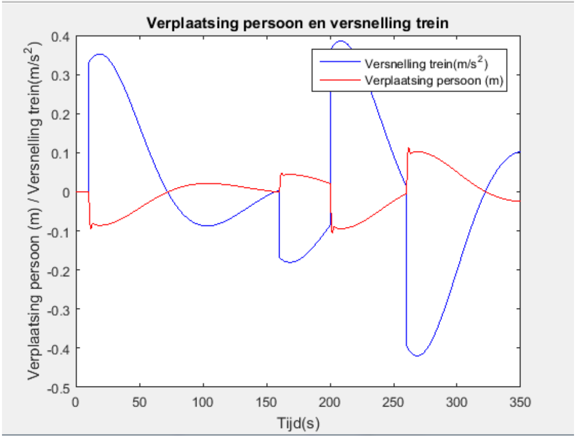
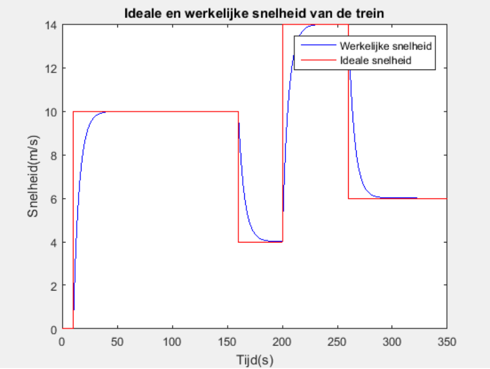


Some Results - Train Velocity

$$\begin{cases} m_{passger} & = 73kg \\ m_{train} & = 6000kg \\ k & = 300 \\ c & = 150 \\ K_p & = 1500 \\ K_i & = 0 \\ K_d & = 2000 \end{cases}$$



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