Universität Stuttgart
Fakultät für Bau- und Umweltingenieurwissenschaften

Nadine García

Development of a simplified physical model of a roller coaster

Motivation

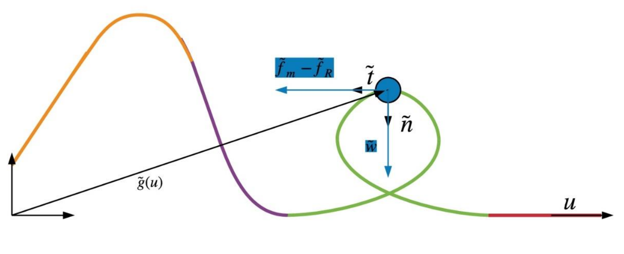
Goal of this thesis was to get familiar with relevant topics in the field of design and simulation of a roller coaster's track and to combine the acquired skills in the implementation of a simplified physical model using MATLAB.

Methodology

First, the relevant physical quantities affecting the train's movement were identified and two different approaches for solving the equations of motion were used.

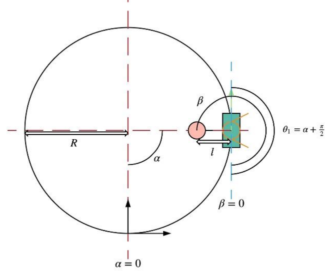
The first one assumed the wagon and the passenger as a point of mass moving along a track defined by a B-Spline Curve. Implementation of this was made in 2D and 3D using Guide App editor in MATLAB, where the user can modify the curve and rolling resistance is considered. The final track contains a chain lift, a looping and a braking area.

$$\ddot{u}(t) = \frac{(\frac{\mathbf{f}(t)}{m} - \mathbf{g}''(u)\,\dot{u}(t)^2)\cdot \mathbf{g}(u)}{(\mathbf{g}'(u)\cdot \mathbf{g}'(u))}$$

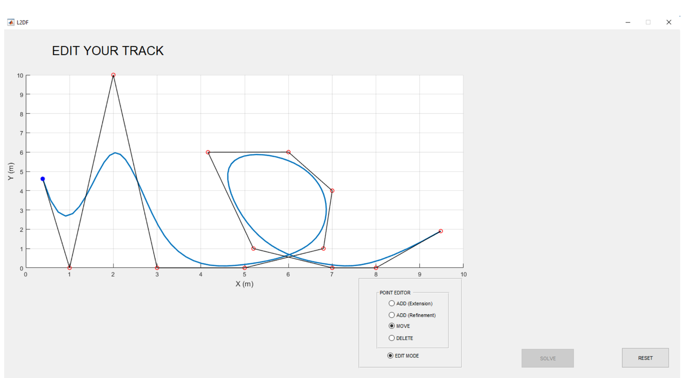

Wagon with a passenger as a point of mass along a B-Spline Curve divided in sections.

The second model consisted on the wagon with a passenger in form of a spring-mass system using the Embedding Technique of Multibody Dynamics on a circle shaped track in 2D. The animation of this model was also implemented.

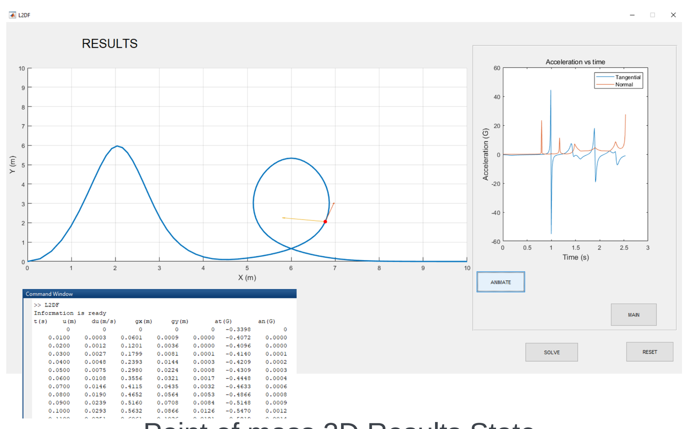
$$\mathbf{M}(\mathbf{y},t)\cdot\ddot{\mathbf{y}} + \mathbf{k}(\mathbf{y},\dot{\mathbf{y}},t) = \mathbf{q}(\mathbf{y},\dot{\mathbf{y}},t)$$
$$\mathbf{M}(\mathbf{y},t) = \sum_{i=1}^{p}[\mathbf{J}_{\mathrm{T}}^{T}\cdot m_i\cdot\mathbf{J}_{\mathrm{T}} + \mathbf{J}_{\mathrm{R}}^{\mathrm{T}}\cdot\mathbf{I}_i\cdot\mathbf{J}_{\mathrm{R}}]$$
$$\mathbf{k} = \sum_{i=1}^{p}[\mathbf{J}_{\mathrm{T}}^{T}\cdot m_i\cdot\bar{\mathbf{a}}_i + \mathbf{J}_{\mathrm{R}}^{\mathrm{T}}\cdot\mathbf{I}_i\cdot\bar{\alpha}_i + \mathbf{J}_{\mathrm{R}}^{\mathrm{T}}\cdot\tilde{\omega}_i\cdot\mathbf{I}\cdot\omega_i]$$
$$\mathbf{q} = \sum_{i=1}^{p}[\mathbf{J}_{\mathrm{T}}^{T}\cdot\mathbf{f}_i^{e} + \mathbf{J}_{\mathrm{R}}^{\mathrm{T}}\cdot\mathbf{l}_i^{e}]$$


Wagon with a passenger in form of a simple spring-mass system

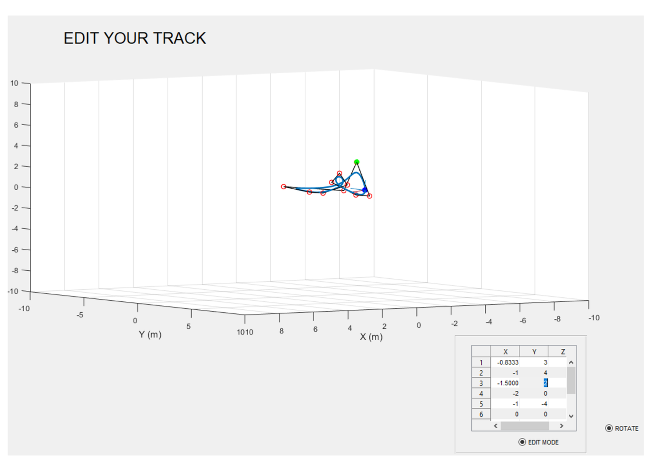
Results



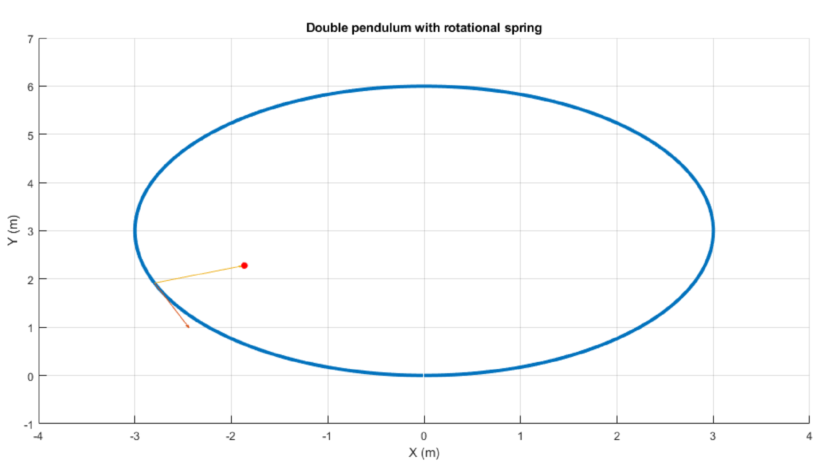
Point of mass 2D B-Spline Editor



Point of mass 2D Results State



Point of mass 3D B-Spline Editor



MBD model simulation

Advisors:

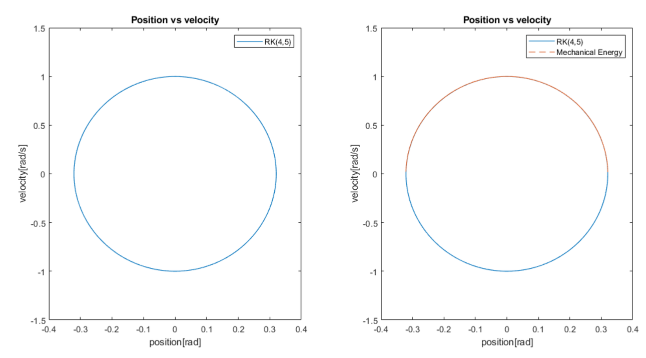
Anne-Kathrin Schäuble, M. Sc.
Rebecca Thierer, M. Sc.

https://www.ibb.uni-stuttgart.de

Numerical Example

Comparison of phase diagrams from numerical scheme RK(4,5) and mechanical energy equation on a circle-shaped track starting from the bottom with different initial velocities and final value of integration $\theta_f = \pi\ [rad]$.

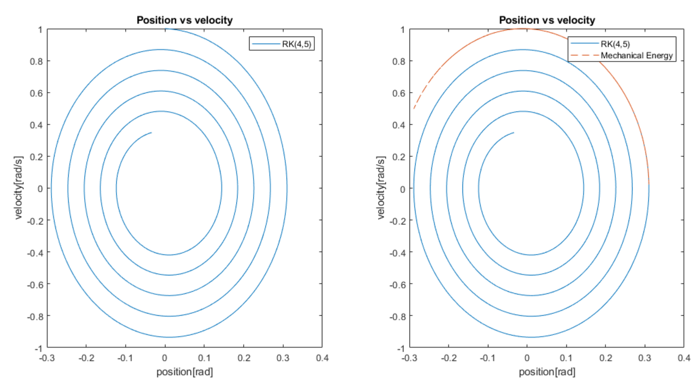
No rolling resistance



$\dot{\theta} = 1\left[\frac{rad}{s}\right]$

$\mu_R = 0.0$

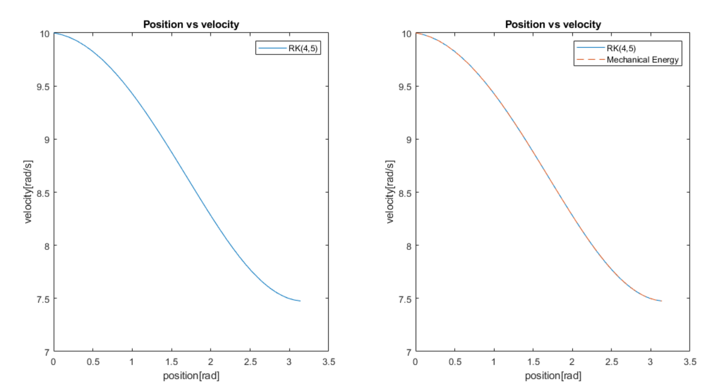
Damped oscillation



$\dot{\theta} = 1\left[\frac{rad}{s}\right]$

$\mu_R = 0.01$

Reach the highest point of the circle



$\dot{\theta} = 10\left[\frac{rad}{s}\right]$

$\mu_R = 0.01$

Literatur

- Eberhard, P. and Seifried, R. (2011). Flexible mehrkörpersysteme. lecture notes.
- Farin, G. (2002). Curves and Surfaces for CAGD, A Practical Guide. Morgan Kaufmann Publishers, San Francisco.
- Klobus, W. (2011). Motion on a vertical loop with friction. American Journal of Physics,79(9):913–918.
- Martin, F. (2012). Spline-modellierung und simulation einer achterbahn.
- Pombo, J. and Ambrósio, J. (2007). Modelling tracks for roller coaster dynamics. J. of Vehicle Design, 45:470–500.
- Weisenberger, N. (2013). Coasters 101, An Engineer's Guide to Roller Coaster Design. Nick Weisenberger.

Baustatik und Baudynamik