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The Segway as a suitable multibody benchmark example

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Abstract
The availability of benchmark problems is largely recognized to be necessary when dealing with simulation software. Hence, the IFToMM TC Multibody Dynamics decided to publish the Library of Computational Benchmark Problems [1] on its website. The purpose of this paper is to propose a scalable collection of problems built around the so-called personal transporter, whose Segway is the most famous commercial implementation.
In the language of mechanics, the personal transporter vehicle can be reduced to 5 different bodies (Figure 1): the main body (denoted here by the passenger), two wheels, and rotors (including the gearbox) of the motors driving the wheels. The fact of including the rotors in the multibody model permits to automatically incorporate the inertia contribution of the DC motors and to naturally apply the magnetic motor torque to the rotors.

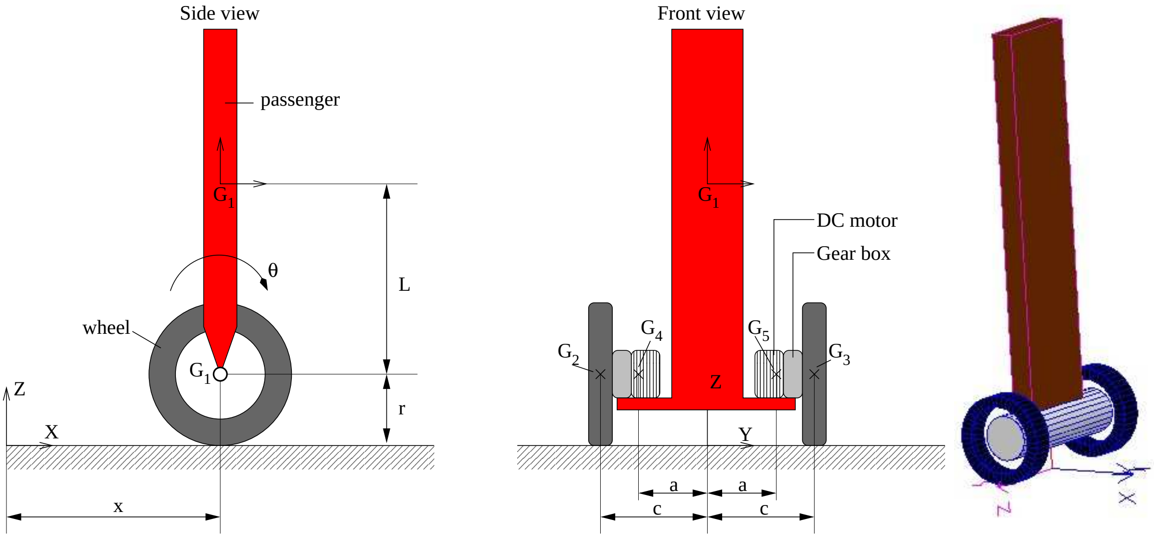

Figure 1: Schematical and 3D view of the Segway vehicle

The personal transporter is interesting as several levels of complexity can be easily defined on the same basis, from a simple 2 DOF system (if the planar motion only is considered and the wheels are assumed to roll without any slip on the ground), to a 8 DOF system if wheels are modelled as tyres in 3D. The equations of the simplest models can even be written manually and integrated in a tool such as `Matlab`, `Scilab` or `Octave`.
Moreover, the system is naturally unstable, like an inverted pendulum, and can only be simulated if a control is applied on the DC motors. Again, several levels will be considered: a simple state feedback regulator making the vehicle going back to a fixed reference position, or a state feedback controller imposing the longitudinal motion in the same time. It is of interest to note that the latter requires its own differential equation to integrate the position error. Practically, the state feedback controller gains are

determined by pole placement or LQG from the linearized equations of motion of the simplest model. In the 3D case, the yaw motion will also be controlled.
Finally, thanks to the complementarity of the tools used in the laboratories of the authors, the simulations will be performed by various multibody codes and compared. The considered packages, as well as the coordinates they are based on, are summarized in Table 1, which also shows the mechanical models for which they are eligible.

Table 1: The summary of possible types of Segway models and computational tools.

	2D model / perfect contact	2D model / tyre	3D model / tyre
EasyDyn (C++, minimal coords.)	✓	✓	✓
MATLAB, minimal coords.	✓	–	–
MATLAB, cartesian coords.	✓	✓	–
alaska (relative coords.)	✓	✓	–
MSC.ADAMS (cartesian coords.)	✓	✓	✓

`MSC.ADAMS` is commercial and very widespread in industry and universities. `EasyDyn` is a simulation framework developed at the University of Mons [2] and available for free on the net. `alaska` (advanced lagrangian solver in kinetic analysis) [4] is a simulation tool for the analysis, the synthesis and the optimization of mechatronical systems. For the development and testing of models and for carrying out interactive analysis `alaska` contains a graphical user interface — the `alaska`/ModellerStudio. As it already was mentioned, simple 2D cases can be analysed under Matlab from equations written by hand. Besides, another in-house modelling tool was also created using `Matlab` at the University of Plzen. It is characterized by the usage of Cartesian coordinates [3], which leads to a system of differential-algebraic equations which can be solved in various ways.

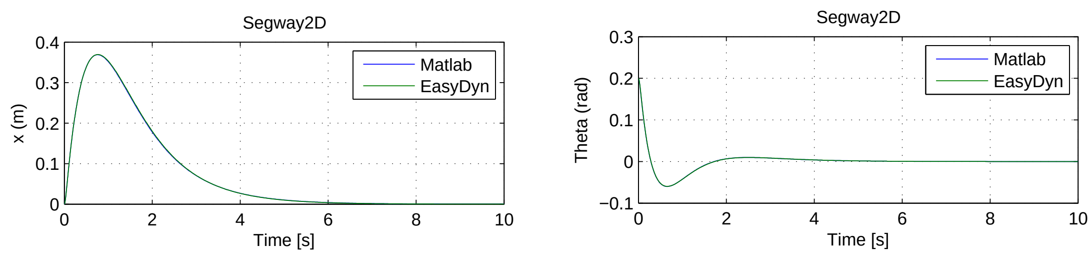

Figure 2: Time histories of *x* and *theta* obtained by `Matlab` and `EasyDyn`

As an example, figure 2 shows the comparison of the results obtained by `Matlab` and `EasyDyn` for the 2D regulated model.

References

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[2] O. Verlinden, G. Kouroussis, C. Conti. Easydyn: a framework based on free symbolic and numerical tools for teaching multibody systems. In: J.M. Goicolea, J. Cuadrado, J.C. García Orden (Eds.) Proceedings of ECCOMAS Thematic Conference Multibody Dynamics 2005, CD-ROM, Madrid, Spain, 2005.

[3] A. A. Shabana. Computational dynamics. Third edition. Wiley, Chichester, 2010.

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