Book of Abstracts

Symposium on High Performance Multibody System Simulation

October 7 – 8, 2022

University of Innsbruck,
Faculty of Engineering Sciences,
Department of Mechatronics,
Technikerstraße 13, 6020 Innsbruck, Austria

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Welcome

The board of the Scientific Committee and the local conference organizers welcome you to the symposium on *High Performance Multibody System Simulation* in Innsbruck, October 7 - 8, 2022. High performance is related to computational methods that boost the performance of simulations, including approaches to increase the performance of small-scale multibody systems as well as HPC approaches for large-scale systems.

Given the success of the previous online symposium in September 2020, we hope that, as previously, up-to-date scientific results will cross-fertilize each other. We keep the symposium light-weight and simple, single-track, no parallel sessions, 15 minutes per talk, roughly same time for discussions, but in comparison to the last online symposium we have now coffee, tea and cookies available.

The meeting takes place in the lecture hall of the University of Innsbruck, Faculty of Engineering Sciences, HSB9, Campus “Technik”, Technikerstr. 13a. The program starts on Friday, October 7, 2022, at 9:10 a.m. with an additional day on Saturday, October 8, featuring the social program with discussions.

Be sure to take advantage of the social activities we have planned for you and take some time to enjoy the magnificent beauty of our surroundings, the Alps. We wish you a stimulating, productive and enjoyable symposium and are looking forward to continue such events in the future.

We are looking forward to meet you in Innsbruck in October!

Scientific Committee

- Olivier Brüls, University of Liège
- Johannes Gerstmayr, University of Innsbruck
- Aki Mikkola, Lappeenranta University of Technology

Local Organizing Committee

- Johannes Gerstmayr, University of Innsbruck
- Michael Pieber, University of Innsbruck

Figure 1: Place of full-day talks: University of Innsbruck and social program: Muttereralm

Sponsors

We thank our sponsors who provided generous support for the conference:

- University of Innsbruck
- Mevea, one of the leading real-time simulation and digital twin technology providers since 2005

General Information

Conference Location

The conference takes place in the lecture halls of the University of Innsbruck, Campus “Technik”:

Gebäude für Technische Wissenschaften[1],
Technikerstraße 13a/b
6020 Innsbruck
Austria

Accommodation

We recommend to book a hotel in the city center. A cheap option is ”Basic Hotel Innsbruck”, a more historic version but more expensive is ”Best Western Plus Hotel Goldener Adler”, and ”Hotel Innsbruck” is in the middle.

Conference Office

The conference office is located in the Gebäude Technische Wissenschaften, 3rd floor, room 323, Technikerstraße 13, 6020 Innsbruck.
The opening hours are

Monday – Tuesday, 8:30 – 12:00.
Thursday – Friday, 8:30 – 12:00.

E-Mail: office-mekt@uibk.ac.at

Get together

Get together of participants takes place on

Friday, October 7, 8:30 – 09:10,

[1]Engineering sciences building

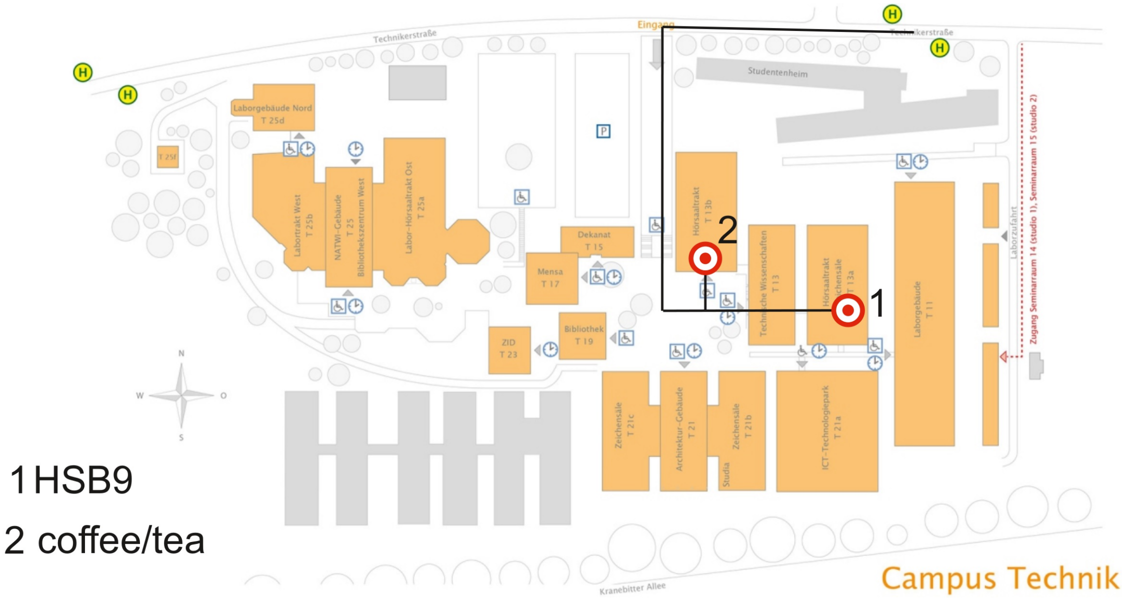

Figure 2: Place of full-day talks: University of Innsbruck, Campus Technik.

in HSB9 in the Gebäude Technische Wissenschaften, Technikerstraße 13a, see Fig. 2.

Further information on the conference can be found at the conference webpage:
`https://www.uibk.ac.at/mechatronik/mekt/hpmbssym2022.html`

Technical Equipment of the Lecture Halls

The room HSB9 is equipped with PC and LCD projector. Acrobat Reader and Power Point are available. The HSB9 is equipped with large blackboards, in addition.

Internet Access during Conference

Eduroam WiFi will be available in the lecture hall.

Lunch and Coffee/Tea Breaks

Small snacks are served for lunch to registered participants on

Friday, 12:45 – 13:45.

Coffee/Tee is served to registered participants on

Friday, 10:55 – 11:15 and 15:30 – 16:00.

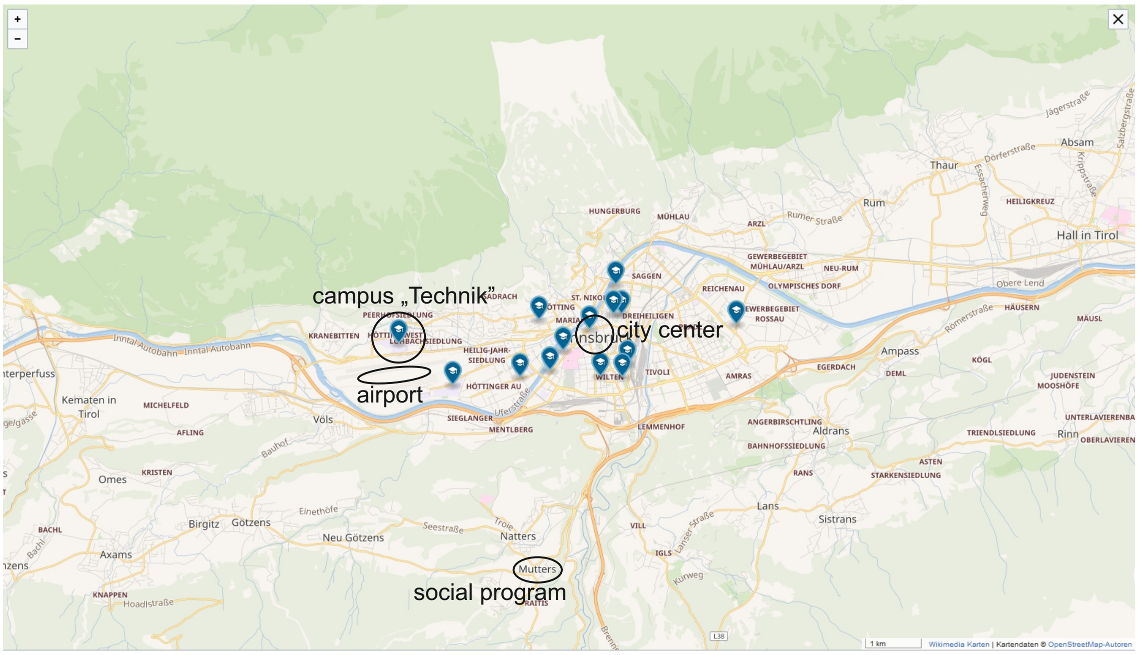

Figure 3: Campus "Technik" is located at the west of Innsbruck.

Local Transportation

Single, 8-way, 24-hours or weekly tickets for bus and tram can be purchased in the local tobacco shops, the ticket machines located at most bus stops, and the IVB Customers Center, Stainerstraße 2. Please consult `http://www.ivb.at/` for detailed information.

To reach the conference location, google maps or navigation apps are recommended.

Information about the Congress Venue Innsbruck

Innsbruck is the capital of Tyrol. For more information about its history and culture please visit the web page of Innsbruck Tourism:

`https://www.innsbruck.info/en/`

Information about the University of Innsbruck

The Leopold-Franzens-University Innsbruck was founded in 1669. Today the University comprises of 16 faculties and 83 departments and is spread around the city of Innsbruck, see Fig. 3. The conference takes place in the lecture halls of the University of Innsbruck, Campus "Technik". For more information about the university, please visit the web page:

`http://www.uibk.ac.at/universitaet/profil/`

Social Program

Conference Dinner

Registered participants of the conference is invited to the Conference Dinner on Friday, October 7 at 19:30. The conference dinner takes place in Restaurant Weisses Rössl, Kiebachgasse 8, 6020 Innsbruck.

The restaurant can be reached on foot (2 minutes from the city center).

Conference Excursion

The conference excursion takes place in the morning of Saturday, October 8. The excursion takes us to Muttereralm.

Departure is from Innsbruck "Terminal Marktplatz" at 09:00, return to the city by 18:00.

Public transport will take us to Mutters. There we have two options to get to Muttereralm. First by cable car with the Mutterer-Alm-Bahn (`https://www.muttereralm.at/en/muttereralm/opening-hours/25-0.html`), or second, with a 2 hours hike (ascent 646 m, 4.5km), see Fig. 4.
After we reach Muttereralm we will hike on easy paths to Pfriemesköpfl (1801m), to a beautiful lake (ascent 180 m, 2.3km) and back to Muttereralm where we will have lunch.
Then have several possibilities to get back down from the mountain.

- First, the easiest option, by cable car with the Mutterer-Alm-Bahn.
- Second, the harder option, with Mountain carts (`https://www.muttereralm.at/en/summer/mountain-carts/56-0.html`).
- Or the last and most difficult option, the third one, by bike (`https://www.muttereralm.at/en/bikepark/trails/103-0.html`). For this option the equipment has to be organized by yourself.

After that we return to Innsbruck. The listed outdoor activities are based on a voluntary basis and no liability is assumed. Regular outdoor shoes and outdoor clothing is recommended.

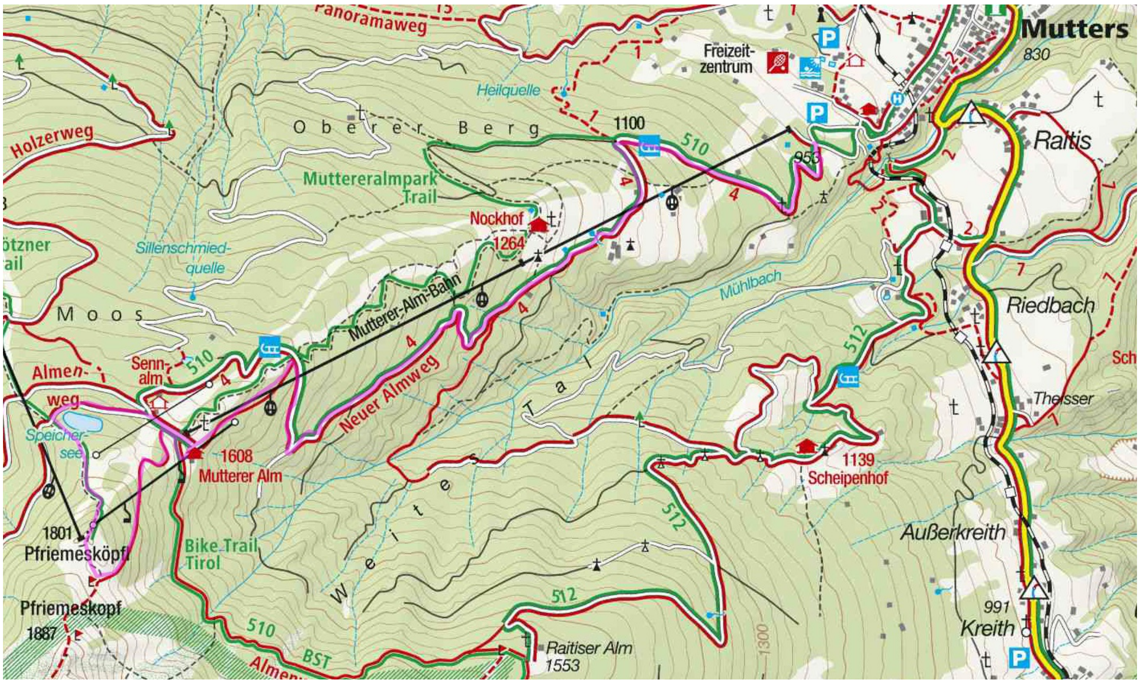

Figure 4: Social program: Muttereralm

Bad weather program

The Tyrolean Panorama and the Kaiserjäger Museum – the Myth of Tyrol and Bergisel ski jump.

Departure is from Innsbruck "Terminal Marktplatz" at 09:00, return to the city by 15:00.

We start from the center of Innsbruck by tram, followed by a 20 minutes' walk to Bergisel ski jump where we can enjoy a breathtaking view of Innsbruck, the fascination of a ski jumping site with an Olympic past and the modern architecture. We devote two hours to the Panorama and the Kaiserjäger museum and have lunch at BERGISEL SKY restaurant with a breathtaking 360-degree view of the entire city.

Abstracts

Efficient Flexible Multibody Impact Simulations Using a Quasistatic Isogeometric Analysis Approach

Nr.1
Oct. 7
9:25

Tobias Rückwald, Alexander Held and Robert Seifried

Institute of Mechanics and Ocean Engineering, Hamburg University of Technology, Eißendorfer Straße 42, 21073 Hamburg, Germany

When performing detailed impact simulations in flexible multibody systems, the deformation of flexible bodies in contact can be described by the isogeometric analysis (IGA) [1,2]. If the floating frame of reference formulation is applied to describe the body kinematics, the deformations are approximated by global shape functions. Rather than full IGA models, shape functions can be obtained by applying a reduction method to the IGA models. The simplest method is modal truncation. However, it cannot represent precise elastic deformations in the contact area. Therefore, Craig-Bampton method should be used instead. The reduced models then consist of low frequency modes representing overall flexibility and high frequency modes representing elastic deformations in the contact area. A major drawback of the Craig-Bampton method is that the resulting equations of motions become numerically stiff, due to the wide frequency range. Large step sizes can be used if the high frequency modes are not yet excited, e.g. two flexible bodies moving towards each other by large rigid body motions. The subsequent contact simulation requires small step sizes and excites the high frequency modes. Therefore, post-contact rigid body motions still require small step sizes. This causes very high computational costs when simulating multiple impacts. One solution for this problem is a quasistatic approach [3]. While this approach has already been successfully applied to isoparametric elements, in the current work the approach is applied to IGA models. Thereby, the precise elastic deformations in the contact area are determined by solving a nonlinear system of equations for the elastic coordinates of the high frequency modes. These elastic coordinates remain quasistatic allowing larger step sizes especially during phases in which no contacts occur.

[1] Cottrell, J.A., Hughes, T.J.R., Bazilevs, Y.: Isogeometric Analysis. John Wiley & Sons, Ltd (2009)

[2] Rückwald, T., Held, A. & Seifried, R.: Flexible multibody impact simulations based on the isogeometric analysis approach. Multibody Syst Dyn 54, 75–95 (2022)

[3] Tschigg, S.: Effiziente Kontaktberechnung in Fexiblen Mehrkörpersystemen (in German). Ph.D. thesis, Hamburg University of Technology (2020)

Nr.2
Oct. 7
9:45

Efficient numerical simulation of flexible multibody systems based on the local frame approach

Valentin Sonneville

Chair of Applied Mechanics, Technical University of Munich, Germany

The finite-element-based formulation of flexible multibody systems is a state-of-the-art, high-fidelity modeling technique that allows arbitrary topologies using essentially geometrically exact flexible components and mechanical joints. Unfortunately, this great accuracy and versatility come at increased computation costs mainly due to the large number of degrees of freedom and the systematic use of Lagrange's multipliers. In this work, drastic reduction in computation time is targeted, based on three key elements. (i) A local frame approach is used, i.e. all derivatives and relative transformations are resolved in local material frames attached to the system components. This choice reduces the nonlinearity of the governing equations for the equations become invariant under rigid-body motions and nonlinearities stem from local effects only. (ii) Thanks to this reduced level of nonlinearity, large parts of the iteration matrix can be considered nearly constant. It is therefore no longer necessary to fully compute and factorize the iteration matrix during a simulation. A domain decomposition procedure is adopted to take advantage of the iteration matrix parts which do not need to be updated. (iii) The domain decomposition implies that many steps of the solution process can be performed in parallel. The performance of the proposed framework is demonstrated on academic and realistic applications.

Nr.3
Oct. 7
10:05

Efficient Adjoint Gradients in a Direct Optimization for Time-Optimal Control Problems in Multibody Dynamics

Karin Nachbagauer[1,2], Daniel Lichtenecker[3] and Philipp Eichmeir[4]

[1]University of Applied Sciences Upper Austria, Campus Wels, Stelzhamerstraße 23, 4600 Wels, Austria

[2]Institute for Advanced Study, Technical University of Munich, Lichtenbergstraße 2a, 85748 Garching, Germany

[3]Technical University of Munich, Germany School of Engineering & Design Department of Mechanical Engineering, Chair of Applied Mechanics

[4]Institute of Mechanics and Mechatronics, Vienna University of Technology, Getreidemarkt 9/E325, 1060 Wien, Austria

The present discussion focuses on time-optimal control problems in multibody systems regarding final constraints. The optimal control problem can be solved e.g. by a direct optimization with the need of a parametrization of the controls transforming the original infinite optimization problem to a finite dimensional one. A

high number of grid nodes leads to a large solution space and therefore to a high computational effort resulting from numerical differentiation with respect to all optimization variables. The present work proposes to use adjoint gradients for the direct solution scheme in order to avoid the high number of function evaluations in the computation of numerical gradients. The analytically derived adjoint gradients will be exploited here for a direct optimization scheme in the sense of a Sequential Quadratic Programming (SQP) solving the time-optimal control problem of a two-arm robot. When comparing the usage of the numerical gradients and the analytically adjoint gradients in the SQP routine, a tremendous reduction of function evaluations and computational time can be observed when using the adjoint gradients to converge to a (local) minimal time.

A time integration scheme for nonsmooth and geometrically nonlinear mechanical systems: from theoretical formulation to software implementation

Nr.4
Oct. 7
11:15

Olivier Brüls[1] and Alejandro Cosimo[2]

[1]Department of Aerospace and Mechanical Engineering, University of Liège, Belgium
[2]Siemens Industry Software NV, Liège, Belgium

This talk presents a transient solver for the simulation flexible multibody systems in the presence of kinematic joints, unilateral contact conditions and highly flexible structural components. The mechanical model may simultaneously include finite rotation and finite motion variables as well as nonsmooth phenomena, with possible jumps in velocities. Finite rotations and motions variables are treated using a Lie group approach while nonsmooth phenomena are treated using the Nonsmooth Generalized-Alpha (NSGA) method.

The time integration scheme is implemented in the open-source code Odin. Some key features which are essential to obtain a robust and CPU-effective implementation are highlighted in the talk. Frictional contact conditions are modelled using an augmented Lagrangian formulation and the time discrete equations are solved using a semi-smooth Newton method. An alternative method, which is currently under development, is to solve the time discrete equations using an iterative Gauss-Seidel.

The behaviour and performance of the method are illustrated using some numerical examples involving contacts between rigid bodies and between elastic beams.

Nr.5
Oct. 7
11:35

Improved performance for simulation of flexible multibody systems

Johannes Gerstmayr

University of Innsbruck, Department of Mechatronics, Technikerstraße 13, 6020 Innsbruck, Austria

There are three common approaches for high performance multibody dynamics simulation. First, there are specialized codes for specific tasks, which are time consuming to be extended. Second, specialized codes use simulator coupling to accomplish complex tasks, however, with inevitable overhead, and serious limitations for extensions, maintainability and lifetime. Third, there are monolithic approaches, restricted by lower performance due to compromises and showing higher complexity. The present talk concerns a monolithic approach, which intends to overcome common limitations of simulation codes regarding complexity and coupling of different modules. Open source codes often consist of a large variety of computational objects, being more than 40 in the current version of Exudyn. Due to the very different nature of such objects, ranging from single degree of freedom masses to complex flexible bodies with model order reduction, a straight-forward GPU implementation is not feasible and hard to be realized within regular research projects – not even thinking about long term maintainability. Nevertheless, one would like to exploit capabilities of current multi-core CPUs, offering at least eight cores, each of which having four arithmetic units or more. The proposed approach to using multithreading is based on a tiny threading library, at which a set of threading units runs during the whole simulation and picks up tasks with nearly no overhead. For this reason, multithreading can be incorporated smoothly into the computation of mass matrices, residuals, Jacobians or contacts, which benefits from parallelization already for comparably small system sizes. Furthermore, a seamless integration of a minimum coordinates formulation into a redundant coordinates framework is shown, offering high performance for small-scale models, such as robots, but still allowing to create any complex multibody system. In order to evaluate the proposed methods, benchmark problems, some of them from the IFToMM multibody benchmark set, will be evaluated. We will show computational results obtained from runs on the inhouse supercomputer using up to 80 cores, both for parallelized single simulations of larger models, as well as for a large number of serial computations done in parallel. Finally, performance on a small cluster is shown.

Half-explicit Runge-Kutta methods for constrained systems on Lie groups

Nr.6
Oct. 7
11:55

Martin Arnold

Martin Luther University Halle-Wittenberg, Germany

Classical higher order time integration methods for ordinary differential equations do not seem to be competitive in the field of high performance computing. On the other hand, these methods have been optimised over decades with respect to accuracy, efficiency and numerical stability and are clearly superior to more simple approaches in the application to smooth problems.

Practical experience has shown that it pays to extend these classical methods from their original field of application to more complex settings like constrained systems or differential equations on manifolds. In the present talk, we recall known facts about higher order half-explicit Runge-Kutta methods for non-stiff constrained mechanical systems and discuss a generalisation that allows to apply these methods efficiently to certain nonlinear configuration spaces with Lie group structure representing, e.g., mechanical systems with large rotations.

States estimation of hydraulic machinery using nonlinear Kalman filters

Nr.7
Oct. 7
14:00

Suraj Jaiswal, Lauri Pyrhönen and Aki Mikkola

Department of Mechanical Engineering, Lappeenranta University of Technology, Finland

Accurate physics-based simulation tools allow product developers to analyze the behavior of the real machinery by creating a virtual copy of the real machine. In heavy machinery, the importance of these simulation models is constantly increasing as they can be used to optimize machine efficiencies, extend machine life, and ensure safe operations. However, simulation models are still only approximations of the real machine behavior and due to small differences, the models diverge from the reality over a long period of time. Nevertheless, information fusion techniques such as state estimators offer a good solution as they combine the information from the simulation model to predict the machine behavior and information from the measurements to correct that prediction. By using this approach, machine manufacturers can get a deep understanding about machine behavior, and this will allow them to improve product development and provide better maintenance and service offerings. The objective of this study is to introduce and compare novel state estimators developed by combining a multibody simulation model with nonlinear Kalman filters in the framework of hydraulic machinery. To this end, an error-state extended Kalman filter (errorEKF) and an unscented Kalman filter (UKF) are covered within the scope of this study. These two Kalman filters differ in nature, where the errorEKF locally linearizes the model in the computation of the state-transition matrix to handle its nonlinearity, whereas the UKF considers the nonlinearity of the model as it is by using a set of sigma points. In other words, the errorEKF is directly dependent on the multibody method utilized, whereas the UKF considers the simulation model as a black box. Consequently, the two estimation algorithms will result in different levels of estimation accuracy and computational efficiency. The estimators are applied to a forestry log crane example. The log crane is modeled using an index-3 augmented Lagrangian-based semi-recursive multibody method, where the hydraulic actuators are modeled using the classical lumped fluid theory.

Data-driven learning of multibody dynamics using deep learning

Nr.8
Oct. 7
14:20

Peter Manzl and Johannes Gerstmayr
University of Innsbruck, Department of Mechatronics, Technikerstraße 13, 6020 Innsbruck, Austria

Methods considered as deep learning or deep neural networks were applied recently to solve differential equations and physical problems in general. We utilize and compare different approaches based on deep learning for learning the behavior of multibody system dynamics from force input data. For that a simple model is used as well as a more complex system containing flexible bodies. Physics informed networks include differential equations in the loss. The gradients of the neural network are used there to calculate the function's derivatives. In the applied frequency based approach the input data of the neural network is transformed into the frequency domain, leading to faster training in our examples.

Planar Multibody Solver Implementation using Fortran, C++, Matlab, and Julia: code efficiency and programming complexity

Nr.9
Oct. 7
14:40

Grzegorz Orzechowski
Department of Mechanical Engineering, LUT University, Yliopistonkatu 34, 53850 Lappeenranta, Finland

Multibody solver implementation is complex and challenging project requiring many decisions. One of the core choices is selection of an appropriate programming language for project needs. This entails available environment, libraries, code complexity, manageability, efficiency, and many others. The objective of this study is to compare implementations of planar multibody solver using popular scientific programming languages: Fortran, C++, Matlab, and Julia. The solver can read model definition from simple text file and perform basic dynamical analysis. It uses reference point coordinates, Baumgarte stabilization technique, and constant step size Runge-Kutta fourth order solver in analysis. The use of external libraries is limited to testing frameworks and linear algebra packages. The work assesses the overall use of the language in multibody application by highlighting the following aspects: ease of use, code clarity and consistency, testability, efficiency, productivity, and others. In the conclusion the main strengths and weaknesses of each language are highlighted to help developers to make more conscious choices. In addition, core development guidelines are emphasized and discussed.

Terramechanics for ground-vehicle simulations

Nr.10
Oct. 7
16:00

Radu Serban, Dan Negrut, Luning Fang, Wei Hu, Ruochun Zhang and Jason Zhou

University of Wisconsin-Madison

We provide an overview of current features, capabilities, and methods in the Chrono physics library, suitable for modeling and simulating deformable terrain and the vehicle-terrain interaction. Chrono provides support for different formulations of deformable soil, from expeditious semi-empirical models to fully resolved granular simulations. A more recent addition, based on a continuous representation of granular dynamics and leveraging the SPH support already available in Chrono, shows great promise in bridging the gap between these two extremes in terms of accuracy and computational efficiency.

Computational efficiency is achieved by suitable choice of formulations, methods, and techniques, appropriate for the respective underlying mathematical model, as well as targeting the hardware best suited for parallelization of the ensuing data structures and algorithms. As such, granular dynamics terrain representations are parallelized either with OpenMP on multi-core processors or else using GPU acceleration with CUDA. The SPH-based continuum representation of granular terrain is a CUDA-based GPU implementation. Finally, the SCM (Soil Contact Model) Chrono implementation leverages multi-core parallelism in its most computationally intensive calculation (namely ray casting in the collision system).

For complex simulations of vehicle mobility on deformable terrain, Chrono has been recently extended with an optional co-simulation framework which allows simulation of various mechanical systems (including full Chrono::Vehicle models) with any of the deformable terrain formulations in Chrono as well as coupled to external, third-party deformable terrain codes. This software infrastructure implements an explicit co-simulation framework and allows seamless switching of the underlying deformable terrain formulation. For flexibility, the co-simulation module uses MPI for inter-module communication and results in a hybrid parallel code, potentially leveraging simultaneously distributed-memory, shared-memory, GPU-accelerated, and instruction-level parallelization.

We provide some insight into the methods and implementations which enable solving complex vehicle mobility problems and demonstrate with illustrative applications.

Nr.11
Oct. 7
16:20

Computational methods for the simulation of nonsmooth cable dynamics in ropeways transportation systems

Vincent Acary[1], Charlélie Bertrand[2], Claude-Henri Lamarque[2] and Alireza Ture Savadkoohi[2]

[1]INRIA Grenoble, France
[2]ENTPE, Lyon, France

Dynamics of cables in ropeways transportation systems is complex. In order to understand the dynamic response of these installations to multiple and coupled loads, such as wind, emergency braking, and cabin-induced vibrations, we have worked on the development of a robust and efficient finite element model of an elastic one-sided cable (only in tension), with boundary conditions of the one-sided contact and Coulomb friction. This numerical model yields a nonsmooth dynamical system and, in practice, to a highly stiff system, given the multi-scales involved, and the elastic stiffnesses of the components. Condition number of the Jacobian matrices of the system are typically larger then 1e10. The simulation of a complete installation is difficult and costly in terms of computational effort, since fine meshes are required for contact areas, and small time steps to ensure a correct integration of the dynamics. Therefore, a computational code taking into account these specificities has been developed in an HPC framework. The different elements of the numerical method will be presented. The presentation will conclude with a set of perspectives such as the development of an inextensible cable model to circumvent stiffness issues, a comparison with geometrically exact beam models and the modelling of the frictional contact in the roller batteries at the level of the whole installation using B-rep description of the multi-body systems.

Nr.12
Oct. 7
16:40

Methods for the Real-Time and Hybrid Co-Simulation of Multibody System Dynamics Applications

Francisco González[1], Antonio J. Rodríguez[1], Borja Rodríguez[2] and Jon García-Urbieta[2]

[1]Laboratorio de Ingeniería Mecánica, Campus Industrial, CITENI, University of A Coruña - 15403 Ferrol, Spain
[2]GKN Automotive Zumaia, 20750 Zumaia, Spain

Co-simulation is a flexible and effective approach to extend the capabilities of multibody system dynamics software. It can be used to provide the ability to consider multiphysics effects, such as hydraulics, electronics, or thermal phenomena, during the dynamics simulation of a mechanical system; it also provides a means to distribute the computational load associated with large problems between several processing units, and to adjust the selection and configuration of solver tools to the particular characteristics of each subdomain under study. Co-simulation requires the careful coordination of the execution of the different solvers to prevent inaccurate and unstable behaviour, especially when iterative coupling schemes cannot be used. This is often the case of real-time and hybrid co-simulation applications, in

which at least one subsystem in the co-simulation environment is a physical, real-world component. Indeed, Human/Hardware-in-the-Loop (HiL) applications such as haptics and cyber-physical systems can be considered instances of hybrid co-simulation setups; cyber-physical benches for the testing of automotive components are a representative example. Depending on factors such as the information that is available to the co-simulation manager, several approaches can be adopted to solve the issues derived from the discrete-time exchange of data at the interface between the subsystems. We provide here an overview of these approaches, and discuss their suitability for their use in practical real-time environments.

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2	Oct. 7	9:45	Valentin Sonneville	Efficient numerical simulation of flexible multibody systems based on the local frame approach
3	Oct. 7	10:05	Karin Nachbagauer, Daniel Lichtenecker and Philipp Eichmeir	Efficient Adjoint Gradients in a Direct Optimization for Time-Optimal Control Problems in Multibody Dynamics
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5	Oct. 7	11:35	Johannes Gerstmayr	Improved performance for simulation of flexible multibody systems
6	Oct. 7	11:55	Martin Arnold	Half-explicit Runge-Kutta methods for constrained systems on Lie groups
7	Oct. 7	14:00	Suraj Jaiswal, Lauri Pyrhönen and Aki Mikkola	States estimation of hydraulic machinery using nonlinear Kalman filters
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9	Oct. 7	14:40	Grzegorz Orzechowski	Planar Multibody Solver Implementation using Fortran, C++, Matlab, and Julia: code efficiency and programming complexity
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