Thematic Conference

Multibody Dynamics 2025

12th ECCOMAS Thematic Conference on Multibody Dynamics

BOOK OF ABSTRACTS

Program included

13 - 18 July 2025
University of Innsbruck | Innsbruck | Austria

edited by
Johannes Gerstmayr - Peter Manzl - Michael Pieber - Andreas Zwölfer

universität innsbruck

Title: Book of Abstracts
12th ECCOMAS Thematic Conference on Multibody Dynamics

Edited by:

Johannes Gerstmayr, University of Innsbruck, Austria
Peter Manzl, University of Innsbruck, Austria
Michael Pieber, University of Innsbruck, Austria
Andreas Zwölfer, Technical University of Munich, Germany

Graphic Design:
Peter Manzl

ISBN:
978-3-200-10587-4

First edition, July 2025

Welcome Message

It is with great pleasure that we welcome you to the **12th** ECCOMAS Thematic Conference on Multibody Dynamics, hosted for the first time in **Innsbruck**, Austria, from July 13 to 18, 2025. This conference has long served as a premier platform for the international multibody community to exchange cutting-edge knowledge and ideas, advancing both the theory and applications of multibody systems.

In the *heart of the Alps*, Innsbruck offers not only a rich scientific environment but also breathtaking natural beauty and a vibrant cultural heritage. We are delighted to host this year's conference in a unique setting and hope it provides both scientific inspiration and a memorable experience for all participants. We are proud to welcome over 270 participants from across the globe, reflecting the truly international and collaborative spirit of our community. The program features plenary talks by renowned speakers and oral sessions showcasing the latest research.

We would like to express our heartfelt gratitude to all those who have made this event possible. First, we thank the Scientific Committee, promoting the conference and ensuring that all relevant topics find their way into the conference schedule. We are also deeply grateful to all the reviewers for their time and effort in assessing the (extended) abstracts and proceedings. We also extend our gratitude to the journal *Multibody System Dynamics* for the support and for publishing the conference's special issue. Additionally, we extend our thanks to the University of Innsbruck, Innsbruck Tourism, and the dedicated staff – especially Tanja Wachter and Wolfgang Markt – as well as colleagues and students who have worked tirelessly to plan and organize this event. Their hard work and commitment have been instrumental in bringing Multibody Dynamics 2025 to life.

Finally, we thank you – the authors, presenters, and participants – for joining us and sharing your latest research and ideas. Your contributions are the heart of this conference, and without you, this event would not be possible. We hope you leave Innsbruck not only with new insights and inspiration for your scientific endeavors but also with fond memories of your time here. Let us continue to build on the ideas shared during this conference and work together to advance the field of multibody dynamics.

Welcome to Innsbruck for Multibody Dynamics 2025,
Johannes Gerstmayr,
Peter Manzl,
Michael Pieber,
Andreas Zwölfer

Contents

Conference Organization

Organizing Committee

Johannes Gerstmayr (general chair), Michael Pieber, Andreas Zwölfer, Peter Manzl, and Tobias Möltner.

Technical and administrative support: Wolfgang Markt and Tanja Wachter.

Scientific Committee

Ambrósio J.A.C. (Portugal)
Bauchau O.A. (USA)
Brüls O. (Belgium)
Cuadrado J. (Spain)
Escalona J.L. (Spain)
Font-Llagunes J.M. (Spain)
Geu Flores F. (Germany)
Kecskeméthy A. (Germany)
Leyendecker S. (Germany)
Liu C. (China)
Meijaard J.P. (Netherlands)
Moosavian S.A.A. (Iran)
Naets F. (Belgium)
Pombo J. (UK)
Serban R. (USA)
Schiehlen W. (Germany)
Shabana A.A. (USA)
Terze Z. (Croatia)
Woernle C. (Germany)
Aoustin Y. (France)
Berbyuk V. (Sweden)
Cardona A. (Argentina)
Dopico D. (Spain)
Fisette P. (Belgium)
Frączek J. (Poland)
Gu Y. (Australia)
Kövecses J. (Canada)
Limebeer D.J.N. (South Africa)
Liu J. (China)
McPhee J. (Canada)
Müller A. (Austria)
Negrut D. (USA)
Poursina M. (Norway)
Sandu C. (USA)
Schwab A.L. (Netherlands)
Sugiyama H. (USA)
Valášek M. (Czech Republic)
Arnold M. (Germany)
Betsch P. (Germany)
Choi J. (Korea)
Eberhard P. (Germany)
Flores J.P. (Portugal)
Gerstmayr J. (Austria)
Jonker B. (Netherlands)
Lankarani H.M. (USA)
Linn J. (Germany)
Masarati P. (Italy)
Mikkola A. (Finland)
Nachbagauer K. (Austria)
Nikravesh P.E. (USA)
Tian Q. (China)
Saha S.K. (India)
Seifried R. (Germany)
Tasora A. (Italy)
García Vallejo D. (Spain)

Conference Information

The conference app Conference4me is available providing an overview of the program including abstracts and proceedings. It is available for Android/iPhone/Windows Phone in the corresponding app-stores. For **latest changes** see the app or the conftool website (`https://www.conftool.com/multibody2025`) under "Conference Agenda".

Venue and Floor Plan

The conference venue Campus Technik (technical campus) is located outside of the city center, close to the airport. It is home to the majority of the natural and engineering sciences in Innsbruck. It is easily reachable by public transport e.g. by the Lines 2, 5 and T. The corresponding stop is simply called *Innsbruck Technik*. Please note that if you are arriving in Innsbruck by plane, there is no direct route to the conference venue, and you will need to navigate around the airport.
The floor plan of the conference venue is shown on page 6. The opening ceremony and first keynote will be in HS A which is in a separate building. Lunch and coffee breaks will be held in HSB 3; while HSB 4 is designated for meetings and is otherwise available for practice. The rooms assigned for each session are listed in the *Scientific Program* section. Please note that HSB 0 is also referred to as "großer Hörsaal".

Wireless Internet Access

At the venue, wireless internet access is available via the international **eduroam** service. In case it is not available for your organization please contact the registration desk.

Instructions for Presenters

Each oral presentation will take 20 minutes including discussion. The lecture rooms contain a Windows PC with Office and Acrobat PDF Reader connected to a data projector. It is not recommended to use your own laptop. To avoid delays in the procedure, please upload and test the slides to the locally available PC before the respective session. Technical support will be provided on-site by the Multibody Dynamics 2025 staff to ensure a smooth delivery of all presentations. Please note also that no more than one oral presentation can be delivered per each registered author.

General Tourist Information

- Tap water in the region is of high quality and safe to drink, originating from the Alps. A reusable metal bottle will be provided to each participant at registration for use during the conference.
- Emergency Phone Number: 112
- Time Zone: UTC/GMT +2 in Summer
- Electricity: 230 V, 50 Hz. Power sockets follow European standards.
- Currency: Euro (€)
- Most places around the city accept both cash and card, but at some (typically remote) locations, only cash is accepted.
- Banks: 08:00 – 12:30 (Monday to Friday)
- Buses: 6:30 – 23:00 (every day; some buses run all night)

Interactive Conference Map

scan/click for interactive map

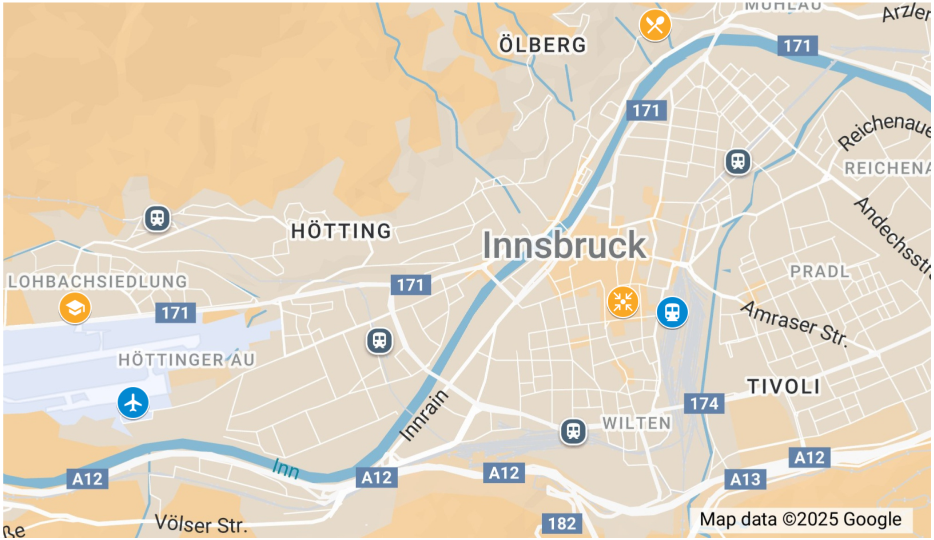
Conference Venue
University of Innsbruck
Technikerstraße 13a

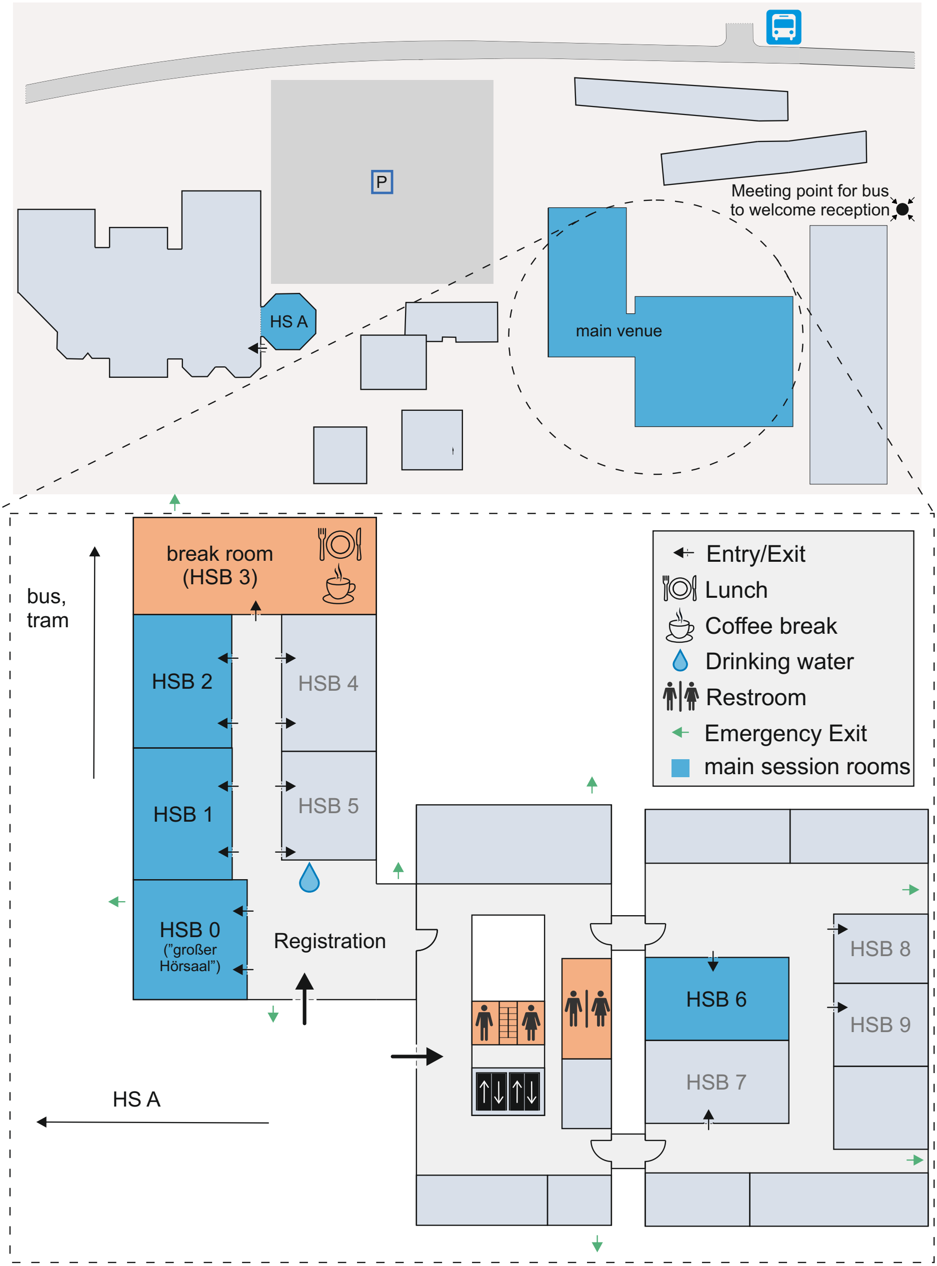
City Tour - Meeting Point
Eduard-Wallnöfer-Platz 2

Dinner
Villa Blanka
Weiherburggasse 8

Airport
Fürstenweg 180

Trainstation
Südtiroler Pl. 5




P
HS A
main venue
Meeting point for bus
to welcome reception
break room
(HSB 3)
bus,
tram
HSB 2
HSB 4
HSB 1
HSB 5
HSB 0
("großer
Hörsaal")
Registration
HS A
HSB 6
HSB 7
HSB 8
HSB 9
Entry/Exit
Lunch
Coffee break
Drinking water
Restroom
Emergency Exit
main session rooms

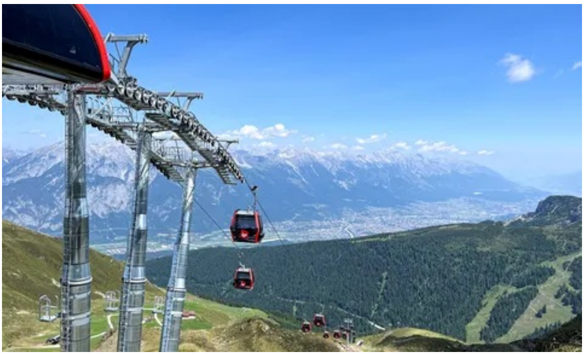
- Pharmacies: 08:00 – 18:00 (Monday to Friday; some are open 24 hours a day, every day)
- Shops: 09:00 – 18:30 (Monday to Friday), 9:00 – 18:00 (Saturdays); note that shops in Austria are closed on Sundays. Exceptions are shops at the clinic and the train station.

Social Programm

Welcome Reception

On Monday afternoon, buses will take the participants to the the welcome reception in the *Axamer Lizum*. From there, the new state-of-the-art 10-seater gondola lift bring us up to the *Hoadl* summit, located at an altitude of 2340 meters, in just a few minutes. At the top, we will enjoy a memorable reception at the Hoadl-Haus, which boasts Austria's largest covered sun terrace. The stunning panoramic views make this a truly unique gathering spot to kick off the conference week. The Hoadl summit is part of the *Kalkkögel*, a beautiful and unique mountain range located southwest of Innsbruck.

Meeting: Monday, July 14th, 17:30, at the conference venue, see also the conference map on page 6.

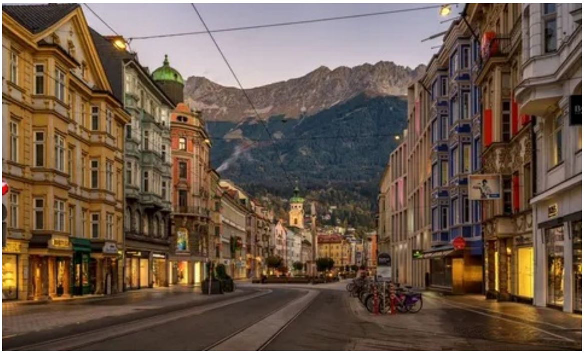


©Axamer Lizum GmbH & Co KG

Explore the City

On Wednesday afternoon a guided city tour is organized, leading us through the historic old town of Innsbruck. It includes some of the most famous sights such as the emblem of Innsbruck, the Golden Roof, and the Hofburg. Please note that signed up participants have a group number printed on their conference badge.

Meeting: Wednesday, July 16th, 16:00, at the *Eduard-Wallnöfer-Platz 2*, see also the conference map on page 5.



©Innsbruck Tourismus / Markus Mair

Conference Dinner

On Wednesday evening, after exploring the city, the conference dinner will take place at *Villa Blanka*, which is located close to the city center and overlooks it. The location is accessible by foot, bus, taxi, or funicular. For detailed directions, please refer to the map on page 11. One scenic option is to follow the shown *Route 2*, which offers a nice walk along the river Inn, but it ends with a slightly steeper ascent. Alternatively the funicular *Hungerburgbahn* can be taken up to the *Alpenzoo* from where one can walk down to the restaurant. The bus line "W" or taxi also lead you directly to the restaurant. The relaxed and welcoming atmosphere of the evening promises an unforgettable evening.

Reception starts Wednesday, July 16th, 18:30 at *Villa Blanka*.

©Villa Blanka

Road to Dinner

Dinner

Hofgarten

Hungerburgbahn

Mariahilfstraße

Alpenzoo

Route 1

A Goldenes Dachl

B1 Innbrücke Bridge

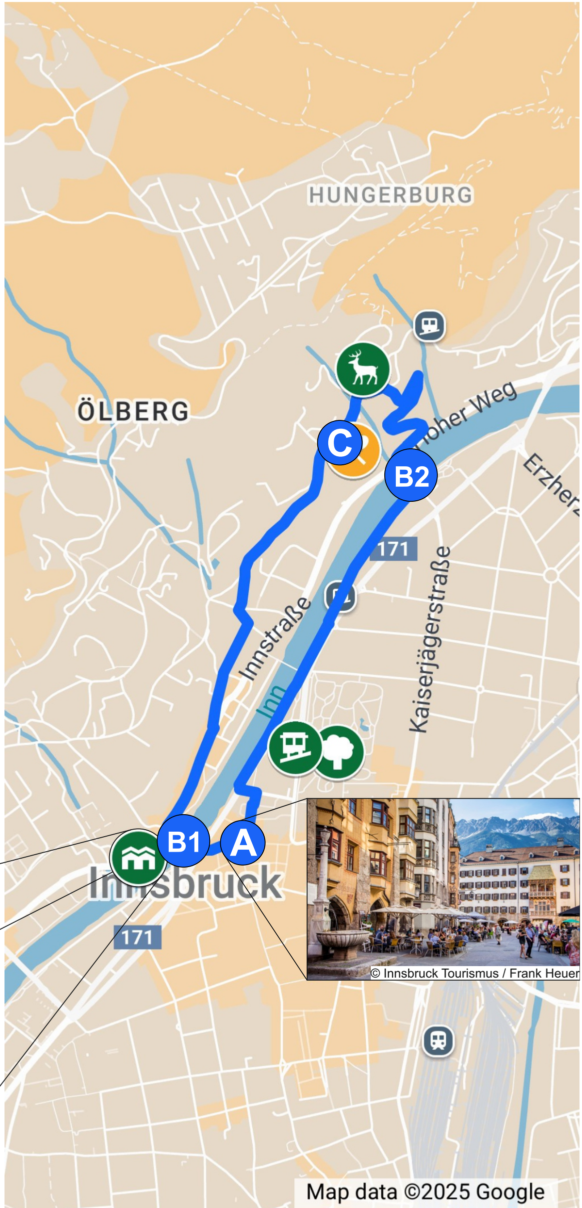
C Dinner: Villa Blanka

Route 2

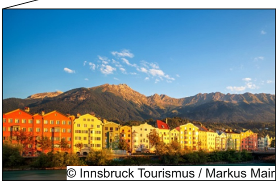
A Goldenes Dachl

B2 Hans-Psenner-Steg

C Dinner: Villa Blanka



© Innsbruck Tourismus / Frank Heuer



© Innsbruck Tourismus / Markus Mair

Scientific Program

In the following chapter the scientific program of the Multibody Dynamics 2025 conference is shown. After the descriptions of the keynotes, the schedules of each day (Mon, Tue, Wed, Thu, Fri) start with an overview table followed by detailed schedules for each session.

Keynotes

Flexible Multibody Dynamics in the port-Hamiltonian Framework

Peter Betsch, Karlsruhe Institute of Technology

The port-Hamiltonian (pH) formalism provides a general framework for the modeling, analysis and control of complex dynamical systems. It generalizes classical Hamiltonian dynamics with respect to dissipative effects and formalizes the interaction between multiple open systems. In the present talk we deal with the pH modeling and space-time discretization of flexible multibody systems. In particular, the geometrically nonlinear Simo-Reissner beam model will be considered as representative structural component of a flexible multibody system. Starting with the pH formulation of the infinite-dimensional beam model the finite element discretization yields a corresponding semi-discrete formulation, retaining the pH structure. We will show that the energy-based pH approach opens new avenues to the design of structure-preserving discretizations in space and time. In particular, a new class of energy-momentum consistent schemes emanating from the pH formulation will be presented.

Making Robots Learn to Perceive and Act with Understanding

Justus Piater, University of Innsbruck

The flexibility and robustness of current robots is limited by their lack of understanding of their environment. For this reason, most robots operate in controlled environments. Machine learning can circumvent modeling problems but introduces new problems of generalizing from examples. How can robots acquire understanding (of structure, function, causality, etc.) that allows them to generalize from sparse experience? Motivated by shortcomings of current machine-learning methods, I will argue that "understanding" is a meaningful notion in AI that reaches beyond prediction and control. I will discuss examples of our recent work on learning visual relational concepts, extrapolation of learned movements beyond the training distribution, learning of symbolic concepts and rules, and structure-driven skill learning from sensorimotor experience. Our long-term objective is to improve abstraction, generalization, robustness, and ultimately explainability of robot perception and action.

Flexible Multibody Dynamics for Space Large Deployable and Assembly Structures

Qiang Tian, Beijing Institute of Technology

With the development of space technology, the demand for large space structures has increased, such as large space telescopes, satellite antennas and space stations. Due to their extremely large size and complex configuration, these structures must be constructed through modular deployment or on-orbit assembly. The flexible multibody dynamics simulation is a key tool, sometimes the only tool, for designing the dynamic characteristics of these structures because of the limitation of the ground experiments caused by gravity. In the framework of flexible multibody dynamics, this presentation first introduces our research team's achievements in the dynamic modeling method for moving flexible bodies. Then, the contact dynamics modeling using the complementary method is described. After that, numerical algorithms, such as variational algorithms, parallelization algorithms developed for different cases are also presented. Finally, some applications, advancements, and experimental verifications are provided.

Adjoint Gradient Computation for Inverse Problems in Multibody System Dynamics

Karin Nachbagauer, University of Applied Sciences Upper Austria

The adjoint method is a powerful optimization technique that differs from classical numerical methods in utilizing adjoint gradients instead of computationally intensive numerical gradients to search for minima (e.g., in time-optimal, energy-minimal, design-optimal optimal controls, or parameter identification). These adjoint gradients capture the sensitivity of the objective function with respect to the system parameters or design variables. Since the dual problem is solved by solving the adjoint equations, whose size is independent of the number of optimization variables, the adjoint method computes the gradients efficiently and is particularly suitable for problems with large models or high-dimensional optimization spaces, where the computational cost of gradient evaluation can be prohibitive. The contribution shows the basic idea of the adjoint method, different use cases and possible extensions for future problems.

Non-Smooth Dynamics: Applications, Challenges, and Future Perspectives

Alessandro Tasora, University of Parma

Non-smooth multibody dynamics is characterized by set-valued force laws and discontinuous impact-like events. It has significant applications across various fields, including robotics, automation, video games, virtual reality and aerospace, to name a few. These systems often involve impacts, friction and other discontinuities that challenge traditional smooth dynamics approaches. The non-smooth nature of these systems presents several challenges, such as the need for advanced numerical methods and computational tools to handle discontinuities and non-linearities, where variational inequalities (often in form of complementarity problems) must be solved at discrete time steps. Future perspectives in non-smooth dynamics research include the development of more efficient complementarity solvers for real-time applications, scalable parallel algorithms for large-scale problems such as granular flows, new time integration methods, more robust and efficient collision detection algorithms, and efficient support of deformable parts with contacts and self-contacts. Applications and practical examples will be discussed.

Time	Sunday July 13
12:00	Workshop Registration
13:00	Workshops
18:00–20:00	Pre-registration & get together

Time	Monday July 14
08:30	**Registration**
09:30	**Opening Ceremony**
10:20	Keynote 1
11:20	Coffee Break
11:50	Session 1
12:50	Lunch
14:00	Session 2
15:40	Coffee Break
	Welcome Reception buses departure no later than 17:30

Time	Tuesday July 15	Wednesday July 16	Thursday July 17	Friday July 18
08:30	Keynote 2	Keynote 3	Keynote 4	Keynote 5
09:40	Session 3	Session 7	Session 10	Session 14
11:00	Coffee Break	Coffee Break	Coffee Break	Coffee Break
11:30	Session 4	Session 8	Session 11	**Closing Ceremony**
12:50	Lunch	Lunch	Lunch	Lunch
14:00	Session 5	Session 9	Session 12	
15:40	Coffee Break		Coffee Break	
16:10	Session 6	16:00-17:15 **Innsbruck Explore the City**	Session 13	
17:50		**Dinner** starting at 18:30		

Day 0: Sunday, July 13 2025

Unlike previous ECCOMAS thematic conferences on multibody dynamics, this year's program includes workshops. Due to a limited capacity of 30 participants per workshop, you can only attend if you are registered for the workshop. Please note that all workshops are fully booked.
The workshops will begin at 13:00, with the registration desk opening for workshop participants at 12:00. General pre-registration for the conference will take place in the evening, starting at 18:00, and will be accompanied by a casual get-together with drinks. This evening event is scheduled to conclude at 20:00.

W1: Workshop on Machine Learning in Multibody Systems

Lecturers: Grzegorz Orzechowski (LUT University) and Peter Manzl (University of Innsbruck)

This hands-on workshop provides a comprehensive introduction to machine learning with a focus on deep learning applications for multibody systems. We give an overview and explore the available toolset for practitioners and researchers in the field of multibody dynamics, and practical applications are shown. This workshop is designed for interested researchers with little to no experience in machine learning and neural networks. Sessions will feature both theoretical information and individual coding for small tasks.

- **Session 1:** Get an introduction to machine learning with an overview of common problems and their associated standard solutions.
- **Session 2:** Explore supervised learning and how neural networks can be used to learn input-output mapping using labeled data from measurements or simulations.
- **Session 3:** Apply Reinforcement Learning (RL) to multibody systems and see how the need for labeled data is bypassed in RL by learning from the interaction with the environment – e.g. a multibody simulation.
- **Session 4:** Get insight into the latest state-of-the-art Large Language Models (LLM), generative text-based models, and their application to the generation of multibody models. In context learning and prompt engineering are applied. The LLMs can be run either locally (if you have a strong laptop) or online using, e.g., ChatGPT or Copilot.

W2: Workshop on Spatial Operator Algebra

Lecturer: Abhinandan Jain (Karana Dynamics, CA; formerly JPL, Pasadena, CA)

Minimal coordinate approaches in multibody dynamics offer numerous benefits, including the elimination of redundant coordinates, compatibility with ODE integrators rather than DAE solvers, rapid solution algorithms, and suitability for embedded applications in robotics and control. Despite these advantages, minimal coordinates are under-utilized and often perceived as intricate, challenging, and having limited applicability to general multibody dynamics problems. This workshop will introduce the Spatial Operator Algebra (SOA) methodology for overcoming these challenges associated with minimal coordinate dynamics. SOA employs a concise set of spatial operators to express and reveal the inherent structure of minimal coordinate dynamics models. These operators generate analytical expressions for critical dynamic quantities such as Jacobians, the mass matrix, its inverse, and others. Notably, the operator expressions and analyses exhibit consistency across the broad spectrum of multibody models ranging from simple serial rigid body systems to complex ones with arbitrary size and topology, and with loop constraints as well as flexible bodies.

The workshop will cover key SOA concepts and techniques that can be used to express system level multibody quantities, analytical techniques for exploiting their structure, and methods to develop low-cost scatter and gather recursive computational algorithms. The focus of the workshop will be on covering foundational ideas and theory to facilitate further exploration of more advanced topics and techniques by the attendees.

W3: Workshop on Flexible Multibody Simulation Tool Exudyn

Lecturer: Johannes Gerstmayr (University of Innsbruck)

We are excited to announce a specialized workshop on the Python package Exudyn, an easy-to-use tool for simulating flexible multibody systems and beyond. Whether you're a seasoned engineer or a researcher in dynamics, this workshop is designed to introduce you to basic architecture of Exudyn as well as hands on modelling of multibody systems with Exudyn. In advanced examples, you can create flexible bodies, including modal reduction, perform parameter optimization, play around with reinforcement learning, or bring your own applications.

- **Session 1:** Introduction to Exudyn: Get acquainted with Exudyn's documentation, capabilities and architecture.
- **Session 2:** Rigid-Body Tutorial: Work through basic tutorials that demonstrate the setup and simulation of rigid-body systems.
- **Session 3:** Advanced Example: Explore a more complex simulation scenario with guidance from experts. Participants are encouraged to bring their own dynamic system problems for discussion and troubleshooting.

Monday

Day 1: Monday, July 14 2025

Overview Scientific Program Monday				
time	room **HSB 0**	room **HSB 1**	room **HSB 2**	room **HSB 6**
09:30 – 10:20	Opening Ceremony HS A			
10:20 – 11:20	**Keynote – Peter Betsch** Flexible Multibody Dynamics in the port-Hamiltonian Framework HS A, chair: Olivier Brüls			
11:20 – 11:50	Coffee Break			
11:50 – 12:50	S1.1: Machine Learning and Artificial Intelligence	S1.2: Multibody Kinematics	S1.3: Optimization and Sensitivity Analysis	S1.4: Dynamics of Vehicles
12:50 – 14:00	Lunch			
14:00 – 15:40	S2.1: Mechatronics, Robotics and Control	S2.2: Aerospace, Medical and Industrial Applications	S2.3: Efficient Simulation and Real-Time Applications	S2.4: Flexible Multibody Dynamics
15:40 – 16:10	Coffee Break			

11:50 – 12:50, HSB 0

S1.1: Machine Learning and Artificial Intelligence

chair: Dan Negrut | co-chair: Grzegorz Orzechowski

ID/🕓	title	authors
200 11:50	Detection of Mechanical Clearances with Data-Driven Approaches	Nguyen, Vuong; Rodríguez, Antonio J.*; Orzechowski, Grzegorz; Mikkola, Aki; Kim, Jin-Gyun; González, Francisco *LUT University
218 12:10	Evaluating Physical, Hybrid, and Data-Driven Models for Rubber-Metal Bushings: Balancing Accuracy, Complexity, and Efficiency	Wohlleben, Meike*; Schütte, Jan; Berkemeier, Manuel; Sextro, Walter; Peitz, Sebastian *Paderborn University
135 12:30	An Interactive Design Assistant for the Synthesis of Four-Bar Linkages Using a Dual-Network Approach	Röder, Benedict; Eberhard, Peter*; Ebel, Henrik *University of Stuttgart

Monday

11:50 – 12:50, HSB 1

S1.2: Multibody Kinematics

chair: Andreas Mueller | co-chair: John McPhee

ID/🕓	title	authors
334 11:50	Kinematics of Single-Degree-of-Freedom Closed-Loop Systems with C2 Hermite Spline Interpolation	Capette, Nicolas*; Houdek, Vaclav; Verlinden, Olivier; Olivier, Bryan *University of Mons
190 12:10	Multibody Modeling of Snapping Linkages	Huczala, Daniel University of Innsbruck
388 12:30	Direct and Inverse Higher-Order Kinematics of Lower-Pair Chain	Condurache, Daniel; Cojocari, Mihail; Popa, Ionuț Technical University Of Iasi

11:50 – 12:50, HSB 2

S1.3: Optimization and Sensitivity Analysis

chair: Janusz Fraczek | co-chair: Daniel Dopico Dopico

ID/🕓	title	authors
159 11:50	Discrete Adjoint Gradients for Constraints Using Implicit Time-Integration	Lichtenecker, Daniel; Nachbagauer, Karin* *University of Applied Sciences Upper Austria
340 12:10	Optimal Design of a Flushing Gate with Variable Counterweight for Self-Actuating Desanding Systems	Gufler, Veit*; Wehrle, Erich; Gufler, Alfred *Free University of Bozen-Bolzano
335 12:30	Impact of Worn Wheel and Rail Profiles on Optimal Steering Parameters of Actively Steered Wheelsets via Sensitivity Analysis	Lindbichler, Lukas; Klanner, Michael; Melito, Gian Marco; Ellermann, Katrin Graz University of Technology

11:50 – 12:50, HSB 6

S1.4: Dynamics of Vehicles

chair: Hiroyuki Sugiyama | co-chair: Taichi Shiiba

ID/🕓	title	authors
395 11:50	Assessment of the Derailment Potential of Freight Wagons Due to Cyclic Top	Pagaimo, João; Magalhaes, Hugo; Infante, Virginia; Ambrósio, Jorge IDMEC, Instituto Superior Técnico
349 12:10	Control Design for Generating Motorcycle Dynamic Data with Realistic Rider Behavior	Schön, Alexander*; Joerg, Hannah *University of Applied Sciences Landshut
389 12:30	Multibody Models for Quantifying and Analysing Railway Odometry System Accuracy	Buset, Alexandre*; Fisette, Paul; Docquier, Nicolas *Université Catholique de Louvain

Monday

14:00 – 15:40, HSB 0

S2.1: Mechatronics, Robotics and Control

chair: Michael Beitelschmidt | co-chair: Ronald Aarts

ID/🕓	title	authors
377 14:00	A Tutorial on the Invariant Filtering Framework	Goffin, Sven*; Barrau, Axel; Bonnabel, Silvère; Brüls, Olivier; Sacré, Pierre *University of Liège
394 14:20	Multibody Model of Mechatronic Pantograph for Railway Operations of with Multiple Pantographs	Ramalho, Pedro; Ambrósio, Jorge*; Antunes, Pedro; Oliveira, Paulo *IDMEC, Instituto Superior Técnico
162 14:40	Line-of-Sight Positioning for Dual Stage Gimbal with Non-Orthogonality Imperfections	Rówienicz, Łukasz*; Malczyk, Paweł *PCO S.A. / Warsaw University of Technology
299 15:00	Robust Speed Control of Multi-Link Mechanism Using H-Infinity Optimization	Hrabačka, Martin; Goubej, Martin; Hajžman, Michal; Dyk, Štěpán; Bulín, Radek University of West Bohemia
123 15:20	Design of a 3-DOF Spatial Manipulator: Torque Minimization for Static and Dynamic Modes	Chesnot, Arthur*; Arakelian, Vigen *INSA Rennes

14:00 – 15:40, HSB 1

S2.2: Aerospace, Medical and Industrial Applications

chair: Peter Eberhard | co-chair: Abhinandan Jain

ID/🕓	title	authors
109 14:00	An Automatic-Differentiation-Based Approach to Simulation of Flexible Multibody Aircraft	Preston, Ben*; Palacios, Rafael; Fasel, Urban; Castrichini, Andrea *Imperial College London
122 14:20	Numerical Whirl-Flutter Investigation of a Multibody/Vortex Particle Tiltrotor Model with Frictional Components	De Vita, Paolo; Cassoni, Gianni; Morandini, Marco; Masarati, Pierangelo*; Fonte, Federico; Favale, Marco; van't'Hoff, Stefan *Politecnico di Milano
176 14:40	Model Predictive Pose Optimisation for Energy Efficient Robotic Machining	Carstensen, Philip*; Seifried, Robert; Möller, Christian; Böhlmann, Christian *Fraunhofer Institute for Manufacturing Technology and Advanced Materials
248 15:00	Dynamic Analysis for Lateral-Torsional Coupled Vibration in a Bolted Joint Dual-Rotor System Considering Interface Multi-Scale Contact State	Zhu, Zhimin; Zhang, Dingguo; Guo, Xian; Li, Liang Nanjing University of Science and Technology
151 15:20	Dynamic Performance Control of the Folding Process for Large Flexible Deployment System	Gao, Chang; Hu, Chenxuan; Gao, Shuojie; Yu, Haidong Shanghai Jiao Tong University

14:00 – 15:40, HSB 2

S2.3: Efficient Simulation and Real-Time Applications

chair: Francisco González | co-chair: Radu Serban

ID/🕓	title	authors
390 14:00	Boosting GPU Parallelization for Real-Time Multibody Simulations Using Leniency: Case Study of Forward Dynamics of a Planar Serial Chain	Guigon, Louis*; Boudon, Benjamin; Mezouar, Youcef; Bouzgarrou, Chedli; Kecskeméthy, Andrés *University of Duisburg-Essen
380 14:20	A Surrogate Modeling Approach in the Real-Time Simulation of Hydraulically Actuated Flexible Systems	Mohammadalizadeh, Mojtaba*; Khadim, Qasim; Mikkola, Aki; Orzechowski, Grzegorz *LUT University
345 14:40	Dynamic Simulation of Constrained Multibody Systems with Electromechanical Actuators Using a Monolithic Approach	García-Agúndez Blanco, Alfonso*; Mikkola, Aki; García-Vallejo, Daniel; Serban, Radu; Mattsson, Aleksi; Peltoniemi, Pasi *LUT University
211 15:00	Towards Real-Time Capable and Physics-Based Terramechanics for Simulating Robot-Terrain Interaction	Unjhawala, Huzaifa Mustafa; Bakke, Luning; Serban, Radu; Yang, Lijing; Hu, Wei; Negrut, Dan* *University of Wisconsin-Madison
147 15:20	Real-Time Virtual Sensor System with Finite Element Model-Driven Digital Twin: Theory, Application and Potentials	Kim, Jin-Gyun; Baek, Hyunwoo; Lee, Ji-won Kyung Hee University

14:00 – 15:40, HSB 6

S2.4: Flexible Multibody Dynamics

chair: Qiang Tian | co-chair: Olivier Bauchau

ID/🕓	title	authors
161 14:00	Flexible Multibody Dynamics of the Enterprise Amusement Ride	Roubos, Harmen; Schilder, Jurnan University of Twente
385 14:20	The Floating Frame of Reference Formulation for Rotordynamics Applications: Limitations and Practical Solutions	Holzinger, Stefan*; Zwölfer, Andreas; Trainotti, Francesco; Gerstmayr, Johannes *Technical University of Munich
297 14:40	A Total Lagrangian Mixed Petrov–Galerkin Cosserat Rod Finite Element Formulation	Herrmann, Marco; Eugster, Simon R. Eindhoven University of Technology
260 15:00	A Modal-Based Approach for the Dynamics of Spur Gears	Serafino, Simone; Fanghella, Pietro; Verotti, Matteo University of Genoa
196 15:20	Dynamic Analysis of Membrane Wing Development Based on Absolute Node Coordinate Formulation	Wang, Bin; Liu, Caishan; Li, Jiaquan Peking University

Day 2: Tuesday, July 15 2025

Overview Scientific Program Tuesday

time	room HSB 0	room HSB 1	room HSB 2	room HSB 6
08:30 – 09:30	**Keynote – Justus Piater** Making Robots Learn to Perceive and Act with Understanding HSB 0, chair: Johannes Gerstmayr			
09:40 – 11:00	S3.1: Machine Learning and Artificial Intelligence	S3.2: Mechatronics, Robotics and Control	S3.3: Optimization and Sensitivity Analysis	S3.4: Formulations and Numerical Methods
11:00 – 11:30	Coffee Break			
11:30 – 12:50	S4.1: Machine Learning and Artificial Intelligence	S4.2: Flexible Multibody Dynamics	S4.3: Contact, Impact and Constraints	S4.4: Formulations and Numerical Methods
12:50 – 14:00	Lunch			
14:00 – 15:40	S5.1: Special Session in Memory of Prof. García de Jalón	S5.2: Multiphysics and Multiscale Problems	S5.4: Multibody Kinematics	
15:40 – 16:10	Coffee Break			
16:10 – 17:50	S6.1: Machine Learning and Artificial Intelligence	S6.2: Flexible Multibody Dynamics	S6.3: Biomechanics	S6.4: Dynamics of Vehicles

09:40 – 11:00, HSB 0

S3.1: Machine Learning and Artificial Intelligence

chair: Henrik Ebel | co-chair: Peter Manzl

ID/🕓	title	authors
326 09:40	Advancing Rail Track Irregularity Classification with Machine Learning and Multibody Simulation Techniques	Torres, João; Pagaimo, João; Magalhães, Hugo; Vieira, Susana IDMEC, Instituto Superior Técnico
384 10:00	Accelerating Multibody Dynamics Simulation Using Deep Learning Surrogate Models	Manzl, Peter*; Humer, Alexander; Khadim, Qasim; Gerstmayr, Johannes *University of Innsbruck
330 10:20	Deep-Koopman-Ehnanced Kalman Filter for Cable-Driven Parallel Robots	Boscariol, Paolo; Dona', Domenico; Richiedei, Dario; Trevisani, Alberto University of Padua
309 10:40	Detecting Cable Failure in Cable Driven Parallel Robots Through Deep Neural Network Classifiers	Bettega, Jason; Richiedei, Dario; Trevisani, Alberto University of Padova

09:40 – 11:00, HSB 1

S3.2: Mechatronics, Robotics and Control

chair: Robert Seifried | co-chair: Sina Ober-Blöbaum

ID/◷	title	authors
307 09:40	Kinematics and Dynamics of a Cable-Driven Floating Platform for Desedimentation	Bieber, Jonas; Bernstein, David; Beitelschmidt, Michael Technische Universität Dresden
271 10:00	Trim Turnpike Property for Mechanical Systems with Symmetries	Maslovskaya, Sofya; Ober-Blöbaum, Sina*; Flaßkamp, Kathrin; Wembe, Boris *Paderborn University
108 10:20	External Force Observer and Control for a Compliant 2-DOF Manipulator	Aarts, Ronald; Dasdemir, Janset University of Twente
286 10:40	Vibration Absorber Actively Converted to Mechanism with Minimal Frictional Effects	Šika, Zbyněk*; Kraus, Karel; Vyhlídal, Tomáš; Michiels, Wim *Czech Technical University in Prague

Tuesday

09:40 – 11:00, HSB 2

S3.3: Optimization and Sensitivity Analysis

chair: Karin Nachbagauer | co-chair: Janusz Fraczek

ID/◷	title	authors
137 09:40	Enhancing Time- And Energy Efficiency by Partially Unconstrained Object Manipulation	Zauner, Klaus; Gattringer, Hubert; Müller, Andreas Johannes Kepler University Linz, Austria
333 10:00	Parameter Optimization of a MWSM Shock-Test Multibody Model Through SRS Analysis	Lopez Varela, Álvaro; Rodriguez González, Antonio; Meijido López, Vicente; Bello Corbeira, Constantino; Dopico Mayobre, Juan; Fariñas Alvariño, Pablo; Cuadrado Aranda, Javier; Dopico Dopico, Daniel* *Universidade da Coruña
308 10:20	Determination of Parameter Sensitivity of Multibody Co-Simulation Models Using the Adjoint Method	Bortels, Daan*; Vanpaemel, Simon; Naets, Frank *E2E Core Lab, Flanders Make
233 10:40	Modeling and Optimal Control of a Vertical Take-Off and Landing UAV	Figat, Marcin; Kania, Katarzyna; Kwiek, Agnieszka; Tarnowski, Andrzej; Pikuliński, Maciej; Malczyk, Paweł Warsaw University of Technology

09:40 – 11:00, HSB 6

S3.4: Formulations and Numerical Methods

chair: Martin Arnold | co-chair: Christoph Woernle

ID/🕓	title	authors
304 09:40	Calculating Higher-Order Time Derivatives of Rigid Multibody Dynamic Equations for Design Purposes	Meijaard, Jacob P.; van der Wijk, Volkert Delft University of Technology
352 10:00	On the Simulation and Analysis of Contact Using an MSD-FEM Co-Simulation Methodology	Melo, Francisco Guedes; Gonçalves, Sérgio Barroso; Areias, Pedro; Silva, Miguel Tavares IDMEC, Instituto Superior Técnico
253 10:20	Analysis of a Ball Vibration Absorber with Focus on Evaluation of the Rolling Condition Boundary	Bulín, Radek; Dyk, Štěpán; Rendl, Jan; Hajžman, Michal University of West Bohemia
172 10:40	Discontinuous Galerkin Method for Flexible Multibody Systems Based on Vectorial Parameterization of Motion	Qi, Yifan; Shan, Minghe; Tian, Qiang Beijing Institute of Technology

11:30 – 12:50, HSB 0

S4.1: Machine Learning and Artificial Intelligence

chair: Grzegorz Orzechowski | co-chair: Henrik Ebel

ID/🕓	title	authors
223 11:30	Control of Underactuated Systems Based on Machine Learning Model: Case Studies	Zelei, Ambrus Szechenyi Istvan University
381 11:50	Surrogate Models for Programmable Structures	Pieber, Michael*; Zhang, Zhaowei; Manzl, Peter; Gerstmayr, Johannes *University of Innsbruck
276 12:10	Efficient Identification of Dynamic Systems: Combining SINDy and Mechanical Knowledge	Plaza, Aitor; Merino-Olagüe, Mikel; Iriarte, Xabier Public University of Navarre
244 12:30	Contact-Rich Assembly Operations Based on Visuotactile Sensing	Guo, Xiaoyue*; Ma, Daolin; Liu, Caishan; Wang, Bin *Peking University

11:30 – 12:50, HSB 1

S4.2: Flexible Multibody Dynamics

chair: Joachim Linn | co-chair: Shilei Han

ID/🕓	title	authors
319 11:30	Efficient Unbalance Variation in Condensed FE Models	Bauer, Klaus-Dieter*; Offner, Günter *Johann Radon Institute for Computational and Applied Mathematics
396 11:50	Sensitivity of Road Vehicles Handling Dynamic Behaviour to Structural Changes	Millan, Pedro; Ambrósio, Jorge IDMEC, Instituto Superior Técnico
290 12:10	An Analytical Method for Planar Motion of Rigid-Plastic Bodies Undergoing Plastic Deformation and Contact Based on the Linear Complementarity Problem	Misaizu, Yuki; Sugawara, Yoshiki*; Takeda, Masakazu; Kitazawa, Yuki *Aoyama Gakuin University
212 12:30	Dynamic Modeling of an Origami-Inspired Microgripper with Curved Creases	Yuan, Tingting*; Liu, Jinyang; Zhang, Wei *Guangxi University

11:30 – 12:50, HSB 2

S4.3: Contact, Impact and Constraints

chair: Alessandro Tasora | co-chair: Olivier Brüls

ID/🕓	title	authors
170 11:30	A Fast Force Gradient Approximation for the Polygonial Contact Model	Grünberger, Jürgen; Steiner, Wolfgang University of Applied Sciences Upper Austria
312 11:50	Simulation of Multibody Systems with Switching Constraints: Formulation and Time Integration	Patil, Indrajeet; Brüls, Olivier University of Liège
265 12:10	On the Regularization of the Coulomb Friction Force Model Using Sigmoid Functions	Novais, Francisco; Marafona, Joao; Silva, Miguel; Flores, Paulo*; Lankarani, Hamid *University of Minho
142 12:30	Hybrid Contact Force Model Based on FrD2 Dynamic Friction Model	Schuderer, Matthias; Rill, Georg; Schulz, Carsten; Schaeffer, Thomas OTH Regensburg

Tuesday

Tuesday

11:30 – 12:50, HSB 6

S4.4: Formulations and Numerical Methods

chair: Andreas Zwölfer | co-chair: Xinxin Yu

ID/◷	title	authors
342 11:30	Variational Integrators for a Lagrangian Formulation of Control Affine Systems with Quadratic Cost	Konopik, Michael; Leyendecker, Sigrid*; Maslovskaya, Sofya; Ober-Blöbaum, Sina; Sato Martín de Almagro, Rodrigo T. *Friedrich-Alexander-Universität Erlangen-Nürnberg
205 11:50	Reaction Uniqueness Problem in the Divide-and-Conquer Approach	Pękal, Marcin; Malczyk, Paweł; Wojtyra, Marek; Frączek, Janusz Warsaw University of Technology
197 12:10	An Updated Lagrangian Conservative Finite Element Method for Hyperelastic Materials	Gabaldon, Felipe; García, Juan Carlos; Arribas, Juan José Universidad Politécnica de Madrid
214 12:30	A Runtime-Optimized Simulation Tool for Determining the Interaction of Catenary and Pantographs	Minor, Lion*; Cleven, Raphael; Doelling, Andre; Corves, Burkhard *RWTH Aachen University

14:00 – 15:40, HSB 0

S5.1: Special Session in Memory of Prof. García de Jalón

chair: José Escalona | co-chair: Pierangelo Masarati

ID/◷	title	authors
434 14:00	Javier García de Jalón, a University Professor Dedicated to His Students	Escalona, José Universidad de Sevilla
131 14:20	Interface Models for the Simulation of Mechanical Clearances	González, Francisco; Rodríguez, Antonio J.; Sanjurjo, Emilio; Naya, Miguel Ángel Universidade da Coruña
375 14:40	Optimization and Optimal Control of a Tilting Vehicle with Flexible Parts	Dopico Dopico, Daniel; Lopez Varela, Alvaro; Luaces Fernancdez, Alberto*; Garcia Orden, Juan Carlos *Universidade da Coruña
121 15:00	A Co-Simulation Algorithm for the Efficient Real-Time Parallel Solution of Multibody Systems	Fontana, Andrea; Morandini, Marco; Masarati, Pierangelo Politecnico di Milano
125 15:20	Historical Evolution of Heavy Machinery and Role of Multibody Dynamics	Jaiswal, Suraj*; Poursina, Mohammad *University of Agder

14:00 – 15:40, HSB 1

S5.2: Multiphysics and Multiscale Problems

chair: Alan Paul Bowling | co-chair: Robert Seifried

ID/🕓	title	authors
119 14:00	Design of a Generic Chrono Framework for Fluid-Solid Interaction	Serban, Radu; Bakke, Luning; Unjhawala, Huzaifa; Negrut, Dan University of Wisconsin-Madison
315 14:20	Some Aspects in Simulation, Design and Control of Wave Energy Converters	Hollm, Marten; Seifried, Robert Hamburg University of Technology
343 14:40	Chrono::DEM: A GPU-Accelerated Multiphysics Solver for Granular Dynamics and Heat Transfer Application	Bakke, Luning; Zhang, Ruochun; Negrut, Dan University of Wisconsin-Madison
228 15:00	Chrono::PowerElectronics an Open-Source Simulation Package for Complex Electro-Mechanical Problems: A Validation Study	Reato, Federico Maria*; Santelia, Matteo; Witt, Bret; Ruiz, Alexis; Ricci, Claudio; Morlacchi, Filippo; Zama, Maurizio; Negrut, Dan *R&D Mechatronics, Iseo Ultimate Access Technologies
246 15:20	Flexible Multibody-Fluid Coupling Dynamics Based on IB-LBM and ANCF	Qin, Yifan; Tian, Qiang; Shan, Minghe; Hu, Haiyan Beijing Institute of Technology

14:00 – 15:40, HSB 6

S5.4: Multibody Kinematics

chair: John McPhee | co-chair: Andreas Mueller

ID/🕓	title	authors
216 14:00	Kinematic Analysis of a Parallel-Actuated Cylindrical Joint	Molla-Santamaria, Paula; Peidro, Adrian; Fabregat-Jaen, Marc; Paya, Luis; Reinoso, Oscar Miguel Hernandez University
337 14:20	Analysis of a Bennett Linkage Using the Geometric Algebra Approach	Alwis Weerasinghe, Sachintha; Dileri, Eirini*; Ebel, Henrik; Poštulka, Tomáš; Huňady, Róbert; Mikkola, Aki; Bauchau, Olivier; Orzechowski, Grzegorz *LUT University
359 14:40	Comparative Multibody Study of Spring Isolation Systems for Vibrating Screens	Galli, Davide*; Nezzi, Chiara; Gufler, Veit; Vidoni, Renato *Free Univeristy of Bozen-Bolzano
351 15:00	A Kinematic Description for Modal-Based Wheels	Bozorgmehri, Babak*; Orzechowski, Grzegorz; Matikainen, Marko K.; Serban, Radu; Mikkola, Aki *LUT University
306 15:20	Kinematics and Motion Planning of a Breeding Blanket Transporter for Remote Maintenance of an EU Fusion Tokamak	Zhang, Xuping Aarhus University

Tuesday

16:10 – 17:50, HSB 0

S6.1: Machine Learning and Artificial Intelligence

chair: Dario Richiedei | co-chair: Grzegorz Orzechowski

ID/🕓	title	authors
239 16:10	PINNs: The Domain Decomposition Approach for Solving Inflatable Membrane Contact Problem	Shen, Xinyi; Sang, Xiaoyu; Liu, Caishan Peking University
393 16:30	Generic Pretrained Reinforcement Learning Agents for Multibody Systems	Weyrer, Sebastian; Manzl, Peter; Gerstmayr, Johannes University of Innsbruck
179 16:50	Online Error Learning for 2DOF Planar Robot Control Using Adjoint Method and Data-Driven Inverse Dynamics	Pikuliński, Maciej; Maciąg, Paweł; Malczyk, Paweł Warsaw University of Technology
259 17:10	Machine Learning Aided Modelling of Mechanical Systems	Merino-Olagüe, Mikel*; Plaza, Aitor; Iriarte, Xabier *Public University of Navarre

16:10 – 17:50, HSB 1

S6.2: Flexible Multibody Dynamics

chair: Peter Betsch | co-chair: Qiang Tian

ID/🕓	title	authors
156 16:10	A 3D Soft DEM for Large-Scale Soft Sphere Dynamics Simulations	Li, Zonglin; Tian, Qiang; Chen, Ju; Hu, Haiyan Beijing Institute of Technology
173 16:30	Viscoelastic Modally-Reduced Nodal-Based Floating Frame of Reference Formulation	Zwölfer, Andreas; Holzinger, Stefan Technical University of Munich
338 16:50	Control Ring and Air Drag Effects on Yarn Balloon Dynamics in Ring Spinning: A Spring-Mass Modeling Approach	Perez-Delgado, Yves Jesus*; Beitelschmidt, Michael; Hossain, Mahmud; Abdkader, Anwar; Cherif, Chokri; Baloochi, Mostafa; Hühne, Ruben *Dresden University of Technology
344 17:10	Reduced-Order Interface Elements for Extremity Solutions in Piezoelectric Beams with Arbitrary Cross-Section	Seinhorst, Bram; Nijenhuis, Marijn; Hakvoort, Wouter University of Twente
149 17:30	Dimensional Reduction of Geometrically Nonlinear Beams: A Center Manifold Approach	Han, Shilei Beijing Institute of Technology

16:10 – 17:50, HSB 2

S6.3: Biomechanics

chair: Sigrid Leyendecker | co-chair: Hamid M. Lankarani

ID/🕓	title	authors
323 16:10	Automated Customization of Human Multibody Models for Optical Motion Capture and Analysis	Beron, Santiago; Lugrís, Urbano; Michaud, Florian; Cuadrado, Javier University of A Coruña
321 16:30	Modelling Dynamic Leg Movements Using Finite Element Analysis of the Achilles Tendon Deformation	Nemov, Alexander; Obrezkov, Leonid; Matikainen, Marko LUT University
300 16:50	Simulating Balancing Movements of Vehicle Occupants	Harant, Monika*; Björkenstam, Staffan; Roller, Michael; Linn, Joachim *Fraunhofer ITWM
275 17:10	Study on Multibody Analysis of Posture Control for Fall Prevention	Kim, Hunhee; Jung, Soonmoon; Kim, Jaemin; Lee, Youngho; Song, Hyeyeong; Oh, Seungyun; Jang, Jiwoo; Na, Inyeop; Lee, Taekyeong; Hong, Junghwa* *Korea University
355 17:30	Compensatory Foot Placement Estimation for Impulsive Torso Perturbation	Goswami, Bhavya Giri; Arami, Arash; McPhee, John University of Waterloo

16:10 – 17:50, HSB 6

S6.4: Dynamics of Vehicles

chair: Taichi Shiiba | co-chair: Hiroyuki Sugiyama

ID/🕓	title	authors
366 16:10	An Analysis of the Mobility Performance of the Apollo Mission Lunar Roving Vehicle (LRV)	Witt, Bret*; Haque, Jamiul; Chen, Patrick; Unjhawala, Huzaifa; Arivoli, Ganesh; Zhang, Harry; Zhou, Zhenhao; Santelia, Matteo; Reato, Federico Maria; Tasora, Alessandro; Bakke, Luning; Serban, Radu; Negrut, Dan *University of Wisconsin-Madison
257 16:30	Development of an Efficient Conformal Contact Model for Railway Applications	Nencioni, Leandro; Meli, Enrico; Cascino, Alessio; Distaso, Francesco; Shi, Zhiyong; Andrea, Rindi Univesity of Florence
320 16:50	Investigation of Model Fidelity and Parameters for Ride Quality Vehicle Models	Jensen, Christian Futtrup; Hansen, Erik Dyreborg; Sirangelo, Dario; Balling, Ole Aarhus University
341 17:10	Thermodynamic Modelling of Degraded Adhesion in Railway Wheel-Rail Contact	Shi, Zhiyong*; Meli, Enrico; Sun, Yu; Rindi, Andrea *University of Florence
348 17:30	Stability Control of Two-Wheeled Trailers with Different Contact Force Models	Horvath, Hanna Zsofia*; Takacs, Denes; Antali, Mate *Budapest University of Technology and Economics

Tuesday

Day 3: Wednesday, July 16 2025

Overview Scientific Program Wednesday				
time	room **HSB 0**	room **HSB 1**	room **HSB 2**	room **HSB 6**
08:30 – 09:30	**Keynote – Qiang Tian** Flexible Multibody Dynamics for Space Large Deployable and Assembly Structures HSB 0, chair: Aki Mikkola			
09:40 – 11:00	S7.1: Flexible Multibody Dynamics	S7.2: Mechatronics, Robotics and Control	S7.3: Contact, Impact and Constraints	S7.4: Dynamics of Vehicles
11:00 – 11:30	Coffee Break			
11:30 – 12:50	S8.1: Flexible Multibody Dynamics	S8.2: Optimization and Sensitivity Analysis	S8.3: Biomechanics	S8.4: Efficient Simulation and Real-Time Applications
12:50 – 14:00	Lunch			
14:00 – 15:00	S9.1: Education, Validation and Software Development	S9.2: Efficient Simulation and Real-Time Applications	S9.4: Dynamics of Vehicles	

09:40 – 11:00, HSB 0

S7.1: Flexible Multibody Dynamics

chair: Stefan Holzinger | co-chair: Peter Betsch

ID/🕓	title	authors
292 09:40	Stress Recovery Based on Linearized Flexible Multibody System Equations	Held, Alexander; Seifried, Robert Hamburg University of Technology
124 10:00	Formulating Finite Elements for Flexible Multibody Dynamics Using Plane-Based Geometric Algebra	Bauchau, Olivier University of Maryland
262 10:20	Development of a Log Crane Based on Flexible Multibody Dynamics and Ultrahigh-Strength Steels	Keränen, Lassi-Pekka; Ikäheimo, Eero; Walica, Dominik; Kurvinen, Emil University of Oulu
155 10:40	A Strain-Continuous Finite Element Formulation of Geometrically Exact Beam Based on Geometrical Hermite Interpolation	Chen, Ju; Huang, Ziheng; Tian, Qiang Beijing Institute of Technology

09:40 – 11:00, HSB 1

S7.2: Mechatronics, Robotics and Control

chair: Michael Beitelschmidt | co-chair: Wolfgang Steiner

ID/🕓	title	authors
278 09:40	Stiffness Control for Inherently Compliant Robots Equipped with Active Magnetic Gears	Kordik, Thomas*; Gattringer, Hubert; Müller, Andreas; Puchhammer, Gregor *Johannes Kepler University Linz, Austria
313 10:00	Applicability and Effectiveness of the Bennet Mechanism	Postulka, Tomas*; Alwis Weerasinghe, Sachintha; Orzechowski, Grzegorz; Mikkola, Aki; Hunady, Robert *VSB – Technical University of Ostrava
136 10:20	Designing a Conditional Obstacle Avoidance for Tracked Vehicles Using Project Chrono and a Neural Network Classifier	Shimada, Shunya*; Zhang, Harry; Negrut, Dan *Komatsu Ltd.
255 10:40	Parameter Identification, Reachable Workspace Analysis, and Trajectory Generation of a Tendon-Driven Soft Continuum Mechanism	Dai, Tianxiang*; Eugster, Simon R.; Leine, Remco I. *University of Stuttgart

Wednesday

09:40 – 11:00, HSB 2

S7.3: Contact, Impact and Constraints

chair: Jorge Ambrósio | co-chair: Mohammad Poursina

ID/🕓	title	authors
371 09:40	Incorporating Friction in Model-Based Co-Simulation of Multi-Domain Mechanical Systems	Raoofian, Ali; Kovecses, Jozsef McGill University
283 10:00	A Novel Frictionless Contact Method for Planar Flexible Bodies	Maddio, Pietro Davide; Cammarata, Alessandro; Sinatra, Rosario University of Catania
160 10:20	Impacts Between Multibody Systems and Deformable Structures	Lipinski, Krzysztof Gdansk University of Technology
363 10:40	A Non-Smooth Approach for Multiphysics Modeling of Tibiofemoral Joint Contact Forces Under Impact Loading	Morshed, Abu Hena MD Maruf; Chatterjee, Abhishek; Ricard, Mark; Prisby, Rhonda; Bowling, Alan* *University of Texas at Arlington

09:40 – 11:00, HSB 6

S7.4: Dynamics of Vehicles

chair: Radu Serban | co-chair: José Escalona

ID/🕓	title	authors
247 09:40	Real-Time Analysis with the Generalized-Alpha Method for Steering Torque Simulator	Shiiba, Taichi; Yazawa, Takuma Meiji University
185 10:00	Use of the Transfer Function of Rail Irregularity to Wheel Acceleration for Track Geometry Inspection	Escalona, José*; Yu, Xinxin; Muñoz, Sergio; Urda, Pedro; Aceituno, Javier; Rodríguez, Miguel *Universidad de Sevilla
269 10:20	Analysis of the Dynamic Response of an Industrial Tow Tractor Through Multibody Simulations	Fidanza, Francesco; Pinelli, Marco; Roychoudhury, Arka; Rivola, Alessandro; Troncossi, Marco; Martini, Alberto* *Toyota Material Handling Manufacturing Italy
241 10:40	Design and Performance Analysis of the Traction System of an Inboard Bogie	Baek, Seung Koo; Jeon, Chang Sung; Shin, Yu Jeong Korea Railroad Research Institute

Wednesday

11:30 – 12:50, HSB 0

S8.1: Flexible Multibody Dynamics

chair: Olivier Bauchau | co-chair: Veit Gufler

ID/🕓	title	authors
229 11:30	Impact of Shear and Extensional Stiffness on Equilibria of Elastic Cosserat Rods - An Update	Linn, Joachim; Roller, Michael; Schneider-Jung, Fabio Fraunhofer ITWM
374 11:50	Accessible Elastic Multibody Modeling of a Pick-and-Place Robot	Hoschek, Sebastian*; Rodegast, Philipp; Frie, Lennart; Pfeifer, Denis; Scheid, Jonas; Schumacher, Ruben; Fehr, Jörg *University of Stuttgart
194 12:10	Dynamic Modeling and Analysis of a Bionic Fish Driven by MFC	Xue, Youcheng; Li, Liang; Zhang, Dingguo; Guo, Xian; Guo, Yongbin Nanjing University of Science and Technology
128 12:30	Dynamic Analysis of a Rotating Mindlin Plate Based on Cell-Based Smoothed Finite Element Method	Du, Chaofan*; Xu, Ningning; Yu, Chuanbin; LI, Liang; Zhang, Dingguo *Yangzhou University

11:30 – 12:50, HSB 1

S8.2: Optimization and Sensitivity Analysis

chair: Daniel Dopico Dopico | co-chair: Jose J Munoz

ID/🕓	title	authors
220 11:30	Numerical Comparison of the Continuous and the Discrete Adjoint Method for Sensitivity Analysis of Multibody Systems Using Various Integration Schemes	Keller, Mirko; Schmidt, Timo Hendrik; Held, Alexander; Seifried, Robert Hamburg University of Technology
144 11:50	Optimization of a Compliant Remote Center of Motion Using Distributed Compliant Mechanisms	Zhang, Zhaowei*; Pieber, Michael; Gerstmayr, Johannes *State Key Laboratory of Robotics
287 12:10	Adjoint Gradient Computation for an Extremal Value of a System Output	Zallinger, Philipp*; Lichtenecker, Daniel; Eichmeir, Philipp; Steiner, Wolfgang; Nachbagauer, Karin *University of Applied Sciences Upper Austria
336 12:30	Discrete Adjoint Sensitivities for Optimal Control of Musculoskeletal Multibody Models	Sonneville, Valentin; Moreno, Benjamin; Brüls, Olivier Universtiy of Liège

11:30 – 12:50, HSB 2

S8.3: Biomechanics

chair: Hamid M. Lankarani | co-chair: Sigrid Leyendecker

ID/🕓	title	authors
386 11:30	Nitsche's Method for Simulation Contact Between the Achilles Sub-Tendons	Obrezkov, Leonid*; Tom, Gustafsson; Rolf, Stenberg; Marko, Matikainen *LUT University
139 11:50	The Effects of Muscle Model and Calibration Strategy on Muscle Fatigue Estimation	Michaud, Florian*; Beron, Santiago; Lugrís, Urbano; Márquez, Gonzalo; Cuadrado, Javier *Universidade da Coruña
391 12:10	Accurate Estimation of Peak Normal Forces During Running Using a Single Foot-Mounted IMU and a Simple Free-Flight/Impact Model with Subsequent ANN Polishing	Ghiassi, Mehdi; Kecskémethy, Andrés University of Duisburg-Essen
213 12:30	Subject-Specific Modeling for the Scoliosis Spine Based on Geometrically Exact Beam Theory	Xiao, Zuming; Guo, Jianqiao*; Guo, Wei; Liu, Xiaomin; Tian, Qiang *Beijing Institute of Technology

11:30 – 12:50, HSB 6

S8.4: Efficient Simulation and Real-Time Applications

chair: Aki Mikkola | co-chair: Radu Serban

ID/🕓	title	authors
153 11:30	Real Experiments with Flexible Multibody System Dynamics Parallelization	Valasek, Michael*; Sargsyan, Artsrun; Mraz, Ladislav *Czech Technical University in Prague
221 11:50	Real-Time Simulation of Flexible Bodies with Ray-Traced Contact in the Unity Game Engine	Zobel, Oliver Maximilian*; Zwölfer, Andreas; Weber, Tobias; Rixen, Daniel *Technical University of Munich
113 12:10	Distributed Hybrid Test of Wind Turbine Pitch Bearing	Kristiansen, Frederik Nordtorp*; Baş, Elif Ecem; Jensen, Per Baunegaard With; Jørgensen, Jan; Gomes, Cláudio Ângelo Gonçalves; Abbiati, Giuseppe *Aarhus University
157 12:30	A Frequency-Based Model Order Reduction Scheme for Dynamic Systems	Masoudi, Ramin American University in Dubai

14:00 – 15:00, HSB 0

S9.1: Education, Validation and Software Development

chair: Alberto Cardona | co-chair: Luning Bakke

ID/🕓	title	authors
339 14:00	A Simplified Implementation of Recursive Dynamics for Flexible Multibody Systems	Yu, Xinxin*; Mikkola, Aki *Tampere University
327 14:20	THREAD - A European Graduate School on Modelling and Simulation of Highly Flexible Structures	Arnold, Martin*; Brüls, Olivier; Celledoni, Elena; Gerstmayr, Johannes; Jelenić, Gordan; Leyendecker, Sigrid; Linn, Joachim *Martin Luther University Halle-Wittenberg
120 14:40	Functional Mock-Up Interface Support in Chrono	Serban, Radu*; Mangoni, Dario *University of Wisconsin-Madison

14:00 – 15:00, HSB 1

S9.2: Efficient Simulation and Real-Time Applications

chair: Francisco González | co-chair: Aki Mikkola

ID/🕓	title	authors
134 14:00	Investigations on Hardware Acceleration for Embedded Simulation of Multibody Dynamics	Kargl, Arnim; Eberhard, Peter University of Stuttgart
169 14:20	Reliable and Smooth Haptic Force Feedback in Interactive Multibody Simulations	Cellupica, Alessio; Cirelli, Marco; Valentini, Pier Paolo University of Rome Tor Vergata
252 14:40	Investigating Subsystem Synthesis Method for Real-Time Multibody Dynamics	Jo, Seongmin*; Han, Seongji; Kim, Jin-Gyun; Kim, Sung-Soo *Kyung Hee University

14:00 – 15:00, HSB 6

S9.4: Dynamics of Vehicles

chair: Jorge Ambrósio | co-chair: Taichi Shiiba

ID/🕓	title	authors
234 14:00	Satellite-Rocket Separation Mechanism Dynamics Analysis and Experimental Verification	Li, Jiaquan; Guo, Xiaoyue; Liu, Caishan Peking University
322 14:20	Reduced Model for Efficient Representation of Flexible Tire-Terrain Interaction	Maleki, Mahdi; Kovecses, Jozsef McGill University
280 14:40	The Applicability of Magnetorheological Elastomers in Suspension Systems for High-speed Train	Shin, Yu Jeong Korea Railroad Research Institute

Day 4: Thursday, July 17 2025

Overview Scientific Program Thursday

time	room HSB 0	room HSB 1	room HSB 2	room HSB 6
08:30 – 09:30	**Keynote – Karin Nachbagauer** Adjoint Gradient Computation for Inverse Problems in Multibody System Dynamics HSB 0, chair: Sigrid Leyendecker			
09:40 – 11:00	S10.1 Flexible Multibody Dynamics	S10.2 Mechatronics, Robotics and Control	S10.3 Contact, Impact and Constraints	S10.4 Formulations and Numerical Methods
11:00 – 11:30	Coffee Break			
11:30 – 12:50	S11.1 Machine Learning and Artificial Intelligence	S11.2 Mechatronics, Robotics and Control	S11.3 Contact, Impact and Constraints	S11.4 Dynamics of Vehicles
12:50 – 14:00	Lunch			
14:00 – 15:40	S12.1 Flexible Multibody Dynamics	S12.2 Aerospace, Medical and Industrial Applications	S12.3 Contact, Impact and Constraints	S12.4 Formulations and Numerical Methods
15:40 – 16:10	Coffee Break			
16:10 – 17:50	S13.1 Flexible Multibody Dynamics	S13.2 Mechatronics, Robotics and Control	S13.4 Biomechanics	

Thursday

09:40 – 11:00, HSB 0

S10.1: Flexible Multibody Dynamics

chair: Jacob P. Meijaard | co-chair: Qiang Tian

ID/🕓	title	authors
291 09:40	Development of a Fast Spring Drive Using Multi-Body Simulation	Gerlach, Erik Rainer; Zentner, Lena TU Ilmenau
324 10:00	Dynamic Analysis of Flexible Forestry Crane Booms with Different Material Assessment	Gupta, Tirtha Sen; Walica, Dominik; Khadim, Qasim; Kurvinen, Emil University of Oulu
272 10:20	Twisted Wire Strands Under Coupled Loading - Experiments and Simulations	Hawwash, Muhannad; Dörlich, Vanessa; Schneider-Jung, Fabio; Linn, Joachim Frauenhofer ITWM

09:40 – 11:00, HSB 1

S10.2: Mechatronics, Robotics and Control

chair: Ronald Aarts | co-chair: Michael Valasek

ID/🕓	title	authors
158 09:40	Modelling and Identification of Passive Effects in Serial Robot Joints and Their Influence on Control	Zavřel, Jan; Bergrová, Šárka; Šika, Zbyněk Czech Technical University in Prague
130 10:00	Simulation and Experimental Validation of a Flexible 5-Bar Parallel Robot	Babut, Alexis*; Boudon, Benjamin; Guigon, Louis; Bouzgarrou, Chedli; Gagnol, Vincent; Hoang, Nguyen Quang *Université Clermont Auvergne
187 10:20	Control of Nonholonomic Systems: Is Model Predictive Control a Universal Solution?	Ebel, Henrik*; Rosenfelder, Mario; Eberhard, Peter *LUT University
186 10:40	Surrogate Model-Based MPC for Precise Maneuvering and Trajectory Tracking in Autonomous Bicycle Control	Miao, Xuyuan; Liu, Caishan Peking University

09:40 – 11:00, HSB 2

S10.3: Contact, Impact and Constraints

chair: Mohammad Poursina | co-chair: Alessandro Tasora

ID/🕓	title	authors
111 09:40	A Novel Implicit Non-Smooth Formulation for Peridynamics with Dual Variables	Tasora, Alessandro; Mangoni, Dario; Fusai, Dario University of Parma
188 10:00	Inverse Dynamic Analysis of a Cycloidal Speed Reducer	Cammarata, Alessandro; Maddio, Pietro Davide; Sinatra, Rosario; Verotti, Matteo*; Serafino, Simone; Fanghella, Pietro *University of Catania
361 10:20	Nonlinear Dynamics of Imperfect Mechanical Systems with Friction	Hajžman, Michal; Hrabačka, Martin; Bulín, Radek; Byrtus, Miroslav; Dyk, Štěpán University of West Bohemia
110 10:40	Anderson-Accelerated Fixed-Point Method for Solving Multibody Problems with Constraints and Contacts	Fusai, Dario; Tasora, Alessandro; Mangoni, Dario; Peng, Chao University of Parma

09:40 – 11:00, HSB 6

S10.4: Formulations and Numerical Methods

chair: Christoph Woernle | co-chair: Andreas Zwölfer

ID/🕓	title	authors
202 09:40	A Novel Kalman Filter Approach for Clearances Estimation	Rodríguez, Antonio J.; Sanjurjo, Emilio*; López-Lombardero, Mario; Cabello, Mario; González, Francisco; Naya, Miguel Ángel *Universidade da Coruña
296 10:00	A Novel Time-Stepping Approach for Mechanical Systems	Solanillas Francés, David Manuel; Kövecses, József McGill University
392 10:20	Galerkin-Based Time Integration Approaches to Rigid Body Dynamics in Terms of Unit Quaternions	May, Marvin; Betsch, Peter Karlsruhe Institute of Technology (KIT)
293 10:40	Application of Servo-Constraints to Model Inversion of Port-Hamiltonian Systems	Hochdahl, René Christopher; Seifried, Robert Hamburg University of Technology

11:30 – 12:50, HSB 0

S11.1: Machine Learning and Artificial Intelligence

chair: Henrik Ebel | co-chair: Dan Negrut

ID/🕓	title	authors
231 11:30	A Study Into the Robustness of Visual-Language Models for Zero Shot Semantic Robot Navigation	Ashokkumar, Sriram; Zhang, Harry; Unjhawala, Huzaifa; Negrut, Dan University of Wisconsin-Madison
387 11:50	Lab in the Loop with Large Language Models and Multibody Simulation	Möltner, Tobias; Pieber, Michael; Manzl, Peter; Gerstmayr, Johannes University of Innsbruck
317 12:10	ChronoLLM: A Framework for Customizing Large Language Models for Digital Twins Based on PyChrono	Wang, Jingquan; Zhang, Harry; Slaton, Khailanii; Wang, Shu; Serban, Radu; Wu, Jinlong; Negrut, Dan University of Wisconsin-Madison
192 12:30	Comparative Analysis of Neural Network-Based and Data-Driven Methodologies for Long-Time Extrapolation in Multibody Dynamics	Choi, Hee-sun*; Jung, Min-Jae; Han, Seok-Hee; Yang, Hyeonseok; Han, Seongji; Kim, Jin-Gyun *Korea Atomic Energy Research Institute (KAERI)

11:30 – 12:50, HSB 1

S11.2: Mechatronics, Robotics and Control

chair: Michael Valasek | co-chair: Michael Beitelschmidt

ID/🕓	title	authors
354 11:30	Energy Efficient Concept of Dual Double Pendulum System with Passive Spring Elements	Krivošej, Jan; Švadlena, Jakub; Šika, Zbyněk Czech Technical University in Prague
353 11:50	A Double Shooting Method for Two-Point Boundary Value Problems in Multibody Dynamics	Eichmeir, Philipp; Steiner, Wolfgang* *Vienna University of Technology
285 12:10	Identification of Friction Forces Within Two Types of Planar Absorber Mechanisms	Kraus, Karel*; Kočandrle, Petr; Šika, Zbyněk *Czech Technical University in Prague
369 12:30	Stability Charts of the Continuous Time Model Predictive Controller	Bodor, Bálint Budapest University of Technology and Economics

11:30 – 12:50, HSB 2

S11.3: Contact, Impact and Constraints

chair: Olivier Brüls | co-chair: Jorge Ambrósio

ID/🕓	title	authors
373 11:30	A Robust Collision Detection Algorithm for Flexible Systems Using Curve-Based Representation	Dai, Xu*; Kövecses, József; Teichmann, Marek *McGill University
301 11:50	A Nonsmooth RATTLE Algorithm for Mechanical Systems with Frictional Unilateral Constraints	Breuling, Jonas; Capobianco, Giuseppe; Eugster, Simon R.*; Leine, Remco I. *University of Stuttgart
166 12:10	An Implicit-Implicit Asynchronous Time Integrator for Multibody Systems with Unilateral Constraints	Wang, Kun; Tian, Qiang Beijing Institute of Technology
282 12:30	Refining Contact Force Models for Energy Dissipation Modelling in Multibody Dynamics	Warzecha, Mariusz AGH University of Krakow

11:30 – 12:50, HSB 6

S11.4: Dynamics of Vehicles

chair: Hiroyuki Sugiyama | co-chair: José Escalona

ID/🕓	title	authors
227 11:30	Floquet Stability Analysis of Simplified Railroad Track Models	Brazales, Álvaro*; Chamorro, Rosario; Fernández, Javier *University of Jaén, Spain
148 11:50	Calculation of the Design Horizontal Geometry of a Railway Track Using Inertial Sensors and GPS Measurements Recorded in Line Vehicles	Rodríguez, Miguel; Urda, Pedro; Escalona, José L. University of Seville
264 12:10	Development of a Wheel-Rail Wear Model Under Conformal Contact Conditions	Distaso, Francesco; Nencioni, Leandro; Cascino, Alessio; Meli, Enrico; Rindi, Andrea University of Florence
226 12:30	Wheel Wear Dynamics in Sharp Curves: Insights From T-Gamma Indicator Study on Heavy-Haul Railways	Pacheco, Philipe Augusto de Paula; Lopes, Mateus Valente; Santos, Auteliano Antunes* *Federal Institute of the Southeast of Minas Gerais

14:00 – 15:40, HSB 0

S12.1: Flexible Multibody Dynamics

chair: Olivier Bauchau | co-chair: Stefan Holzinger

ID/🕓	title	authors
225 14:00	Prediction of the Wear Behavior of a Conveyor Belt with Flexible Rollers	Vogl, Yannick Marius*; Schulz, Carsten; Schaeffer, Thomas; Geiger, Benjamin *OTH Regensburg
164 14:20	A Curvilinear Beam Finite Element for Geometrically Nonlinear Static and Dynamics Analysis of Flexible Multibody Systems	Iandiorio, Christian*; Salvini, Pietro; Botta, Fabio; Valentini, Pier Paolo *University of Rome Tor Vergata
118 14:40	Efficient Multi-Body Dynamics Analysis Using a Data-Driven Component Meta-Model for Flexible Bodies	Choi, Juhwan*; Jang, Kyungchun; Kim, Seongsu; Choi, Jin Hwan *FunctionBay, Inc.
273 15:00	Higher Order Model Reduction with a Mixed Formulation for Large Deflection Mechanisms	Dwarshuis, Koen; Nijenhuis, Marijn University of Twente
183 15:20	Vibration Analysis and Electrode Arrangement of Rotating Piezoelectric Laminated Micro-Beams	Liu, Haocheng*; Chen, Yuanzhao; Zhang, Dingguo; Guo, Xian; Li, Liang *Nanjing University of Science and Technology

14:00 – 15:40, HSB 1

S12.2: Aerospace, Medical and Industrial Applications

chair: Pierangelo Masarati | co-chair: Peter Eberhard

ID/⏲	title	authors
114 14:00	Coupled Simulation of Steady Helicopter Forward Flight for Vibration Analyses	Frie, Lennart*; Wengrzyn, Oskar; Keßler, Manuel; Eberhard, Peter *University of Stuttgart
288 14:20	Multibody Dynamic & Aerodynamic Modeling of a Tube-Launched Sweep Morphing Unmanned Aerial System	van Elsloo, Samuel Johannes*; van Rooij, Michel; Hamraz, Ash; De Breuker, Roeland; Voskuijl, Mark *Delft University of Technology
180 14:40	Dynamic Analysis of Coupled Vibration Instability in Rolling Mill	Arora, Rohit Mitsubishi Heavy Industries
168 15:00	Improving the Vibration Performance of an Artwork Transport Crate	Ziegler, Pascal*; Gao, Yulong; Velte, Stefan; Eberhard, Peter *University of Stuttgart
146 15:20	A Compliant Control Strategy for On-Orbit Assembly of Multi-Interface Modules Based on Residual Reinforcement Learning Compensation	Yan, Xinle*; Shi, Lingling; Shan, Minghe *Beijing Institute of Technology

14:00 – 15:40, HSB 2

S12.3: Contact, Impact and Constraints

chair: Paulo Flores | co-chair: Mohammad Poursina

ID/⏲	title	authors
152 14:00	The Impact of Manufacturing Inaccuracies and Thermal Expansion on Joint Loads Within Overconstrained Multibody Systems—a Case Study	Wojtyra, Marek; Pękal, Marcin Warsaw University of Technology
298 14:20	On Coupling Effect of Variables in Contact Force Laws	Antali, Mate Szechenyi Istvan University
217 14:40	An Efficient Reconstruction Scheme of Signed Distance Fields for Contact Detection Between Flexible Bodies	Tang, Tiantian; Luo, Kai; Tian, Qiang; Hu, Haiyan Beijing Institute of Technology
311 15:00	Comparative Analysis of Programming Languages for Multibody Dynamics with Contact Events: Matlab vs. Julia	Gismeros Moreno, Raúl*; Corral Abad, Eduardo; Gómez García, María Jesús; Castejón, Cristina *Universidad Carlos III de Madrid
378 15:20	Several Continuous Contact Force Models for Impact in Multibody Systems	Nikravesh, Parviz; Poursina, Mohammad* *University of Arizona

14:00 – 15:40, HSB 6

S12.4: Formulations and Numerical Methods

chair: Martin Arnold | co-chair: Andreas Zwölfer

ID/🕓	title	authors
294 14:00	Towards a Quasi-Static ALE-frictional Formulation for Cable-Actuated Multibody Systems	Devigne, Olivier; Brüls, Olivier University of Liège
318 14:20	Design Evaluation of Aircraft Seat Safety Using a Plastic Hinge Multibody Model	Martins, Ana*; Carvalho, Marta; Olivares, Gerardo; Lankarani, Hamid *NOVA School of Science and Technology
154 14:40	Parallelization of a Multi-Flexible-Body Framework on Distributed Memory Architectures Using MPI	Mangoni, Dario; Tasora, Alessandro; Fusai, Dario University of Parma
107 15:00	Tangent Stiffness Matrix of Holonomic Constraints and Its Impact on Static and Eigenvalue Problems	Peng, Chao*; Tasora, Alessandro; Mangoni, Dario; Fusai, Dario *University Of Parma
199 15:20	Port-Hamiltonian Formulation and Structure-Preserving Discretization of Geometrically Exact Beams	Kinon, Philipp L.*; Betsch, Peter; Eugster, Simon R. *Karlsruhe Institute of Technology (KIT)

16:10 – 17:50, HSB 0

S13.1: Flexible Multibody Dynamics

chair: Alexander Held | co-chair: Joachim Linn

ID/🕓	title	authors
112 16:10	Approximating the Inertia Forces in the Floating Frame Formulation Using Finite Elements with Rotational Degrees of Freedom	Van Voorthuizen, Karlijn; Abdul Rasheed, Mohammed Iqbal; Schilder, Jurnan; Ellenbroek, Marcel University of Twente
175 16:30	A Concept of the Metamodel Based on the Dynamics Analysis Results of the Eccentric Crank-Rocker Mechanism	Urbaś, Andrzej; Stadnicki, Jacek University of Bielsko-Biala
302 16:50	Theoretical and Computational Aspects in a Mechanical Network Model of Compliant Mechanisms	Sorgonà, Orazio*; Giannini, Oliviero; Verotti, Matteo *Niccolò Cusano University of Rome
240 17:10	Modal Reduction for Geometrically Nonlinear Slender Structures	Otsuka, Keisuke*; Sugiyama, Hiroyuki *Tohoku University
279 17:30	Development of a Hybrid Mooring Line Model Based on the Incremental Form of Finite Rotation	Hara, Kensuke Central Research Institute of Electric Power Industry

16:10 – 17:50, HSB 1

S13.2: Mechatronics, Robotics and Control

chair: Wolfgang Steiner | co-chair: Michael Pieber

ID/🕓	title	authors
207 16:10	Active Vibration and Active Structural Acoustic Control of Simply Supported Plates	Hirschfeldt, Natasha; Furtmüller, Thomas; Adam, Christoph Universität Innsbruck
372 16:30	Control-Oriented Linearization Method for Multibody Models	Kuslits, Márton University of Surrey
219 16:50	Modeling and Experiments on Stable Stepladder Walking	Polach, Pavel*; Papáček, Štěpán; Anderle, Milan *Research and Testing Institute Plzen
284 17:10	Energy-Saving Control of a Robot Manipulator with Biarticular Muscle-Like Springs Imitating the Human Upper Limbs	Dozono, Chikako; Tanizaki, Kenshu; Iwamura, Makoto Fukuoka University

16:10 – 17:50, HSB 6

S13.4: Biomechanics

chair: Sigrid Leyendecker | co-chair: Hamid M. Lankarani

ID/🕓	title	authors
379 16:10	Model Predictive Control of Dorsiflexion and Plantarflexion of a Human Foot	Shakeel, Muhammad Uzair*; Ebel, Henrik; Khair, Ra'ad M.; Nemov, Alexander; Finni, Taija; Matikainen, Marko *LUT University
362 16:30	Modeling Musculoskeletal Systems Using a Multibody Formulation with Fully Cartesian Coordinates and a Generic Rigid Body	B. Gonçalves, Sérgio*; Flores, Paulo; Silva, Miguel Tavares da *IDMEC, Instituto Superior Técnico
210 16:50	Flexible Multibody Dynamic Modeling of Mandibular Musculoskeletal System in Mandibular Fracture Patients and Its Utilization in Fixation Design	Wang, Xinyue*; Liu, Lu; Guo, Jianqiao; Wang, Xinyu; Tian, Qiang *Beijing Institute of Technology
364 17:10	A New Hip Cable-Driven Wearable Assistive Device to Reinforce Human Balance	Muscolo, Giovanni Gerardo; Sancisi, Nicola; Conconi, Michele*; Del Felice, Alessandra; Chiari, Lorenzo *Università di Bologna
305 17:30	Comparative Study of Two Biomechanics Frameworks for Upper Limb Exoskeleton Simulations	Moreno, Benjamin; Sonneville, Valentin; Foguenne, Léonore; Schwartz, Cédric; Sacré, Pierre; Brüls, Olivier University of Liège

Day 5: Friday, July 18 2025

Overview Scientific Program Friday				
time	room **HSB 0**	room **HSB 1**	room **HSB 2**	room **HSB 6**
08:30 – 09:30	**Keynote – Alessandro Tasora** Non-Smooth Dynamics: Applications, Challenges, and Future Perspectives HSB 0, chair: Radu Serban			
09:40 – 11:00	S14.1 Machine Learning and Artificial Intelligence	S14.2 Optimization and Sensitivity Analysis	S14.3 Contact, Impact and Constraints	S14.4 Formulations and Numerical Methods
11:00 – 11:30	Coffee Break			
11:30 – 12:50	Closing Ceremony HSB 0			
12:50 – 14:00	Lunch			

09:40 – 11:00, HSB 0

S14.1: Machine Learning and Artificial Intelligence

chair: Peter Manzl | co-chair: Dan Negrut

ID/🕓	title	authors
150 09:40	Data-Driven Hydrodynamics Model for Prediction of Vehicle-Water Interaction	Yamashita, Hiroki; Harwood, Casey; Martin, Juan Ezequiel; Tison, Nathan; Grunin, Arkady; Jayakumar, Paramsothy; Sugiyama, Hiroyuki* *University of Iowa
367 10:00	Hybrid NN-EOM Approach to Accelerate Multi-Body Simulations	Slimak, Tomas; Todorov, Bojidar; Zwölfer, Andreas Technical University of Munich
167 10:20	Identification of Friction in Joints for Multibody Dynamics: An Adjoint-Based ANN Approach	Sun, Guangxin; Ding, Yuxuan; Han, Shilei Beijing Institute of Technology
140 10:40	Physics-Inspired Data-Driven Modeling of Complex Mechanical Components for Integration in Multibody Dynamic Simulations	Vanpaemel, Simon*; Kutz, J. Nathan; Brunton, Steven L. *KU Leuven

09:40 – 11:00, HSB 1

S14.2: Optimization and Sensitivity Analysis

chair: Valentin Sonneville | co-chair: Karin Nachbagauer

ID/🕓	title	authors
174 09:40	Eigenvalue Shift Using the Eigenvalue Perturbation	Schulz, Carsten; Graneß, Henry; Weinzierl, Stefan*; Nicklas, Johannes *Regensburg University of Applied Sciences
370 10:00	Force and Friction Inference in Worm Locomotion	Munoz, Jose J*; Krieg, Michael; Paddle, Aleksandra *Universitat Politècnica de Catalunya
235 10:20	Practical Computation of Initial Sensitivities in Dynamics of Flexible Multibody Systems	García Orden, Juan Carlos; Arribas Montejo, Juan José; Felipe, Gabaldón Castillo; Daniel, Dopico Dopico Universidad Politécnica de Madrid
266 10:40	Integration of Fatigue Analysis in the Structural Optimization of Railway Vehicles Components: Development and Application of a New Methodology	Cascino, Alessio; Nencioni, Leandro; Tafa, Idriz; Distaso, Francesco; Meli, Enrico; Rindi, Andrea Università degli studi di Firenze

09:40 – 11:00, HSB 2

S14.3: Contact, Impact and Constraints

chair: Simon R. Eugster | co-chair: Mohammad Poursina

ID/🕓	title	authors
116 09:40	A New Method for the Calculation of Contact Forces in the Non-Smooth Dynamics Approach	Sánchez, Eliana Selen; Cavalieri, Federico Jose; Cardona, Alberto Universidad Nacional del Litoral-CONICET
138 10:00	A Scaled Boundary-Finite Cell Approach for 2D Contact Dynamics with Large Deformations and Complex Interfaces	Feng, Yue; Wang, Kun; Tian, Qiang; Hu, Haiyan Beijing Institute of Technology
232 10:20	Multi-Body Pseudo-Rigid Modeling of Helical Gears	D'Angelo, Luca; Autiero, Matteo; Cirelli, Marco; Paoli, Giovanni; Valentini, Pier Paolo University of Rome Tor Vergata
281 10:40	Microgravity Experiments for Contact Dynamics Characterization in the Asteroid Environment	Vaghi, Samuele; Cremasco, Alessia; Delfanti, Luigi Vittorio; Fodde, Iosto; Ferrari, Fabio Politecnico di Milano

09:40 – 11:00, HSB 6

S14.4: Formulations and Numerical Methods

chair: Xinxin Yu | co-chair: Martin Arnold

ID/🕓	title	authors
132 09:40	A Novel Eulerian Newmark Scheme for Cosserat Beams	Cammarata, Alessandro; Greco, Leopoldo; Castello, Domenico; Cuomo, Massimo Università di Catania
143 10:00	Spatial Distribution of Control Loads to Stabilize an Unconstrained Multibody Simulation	Bolk, Johannes; Corves, Burkhard RWTH Aachen University
289 10:20	Optimization-Based Identification of Low-Dimensional Port-Hamiltonian Systems	Rettberg, Johannes*; Sharma, Harsh; Fehr, Jörg; Krämer, Boris *University of Stuttgart
329 10:40	Application of the Extended Kalman Filter for Constraint Enforcement in the Forward Dynamics of Multibody Systems	Richiedei, Dario; Tamellin, Iacopo*; Trevisani, Alberto *University of Padova

Abstracts

Abstract ID: 107

Tangent Stiffness Matrix of Holonomic Constraints and Its Impact on Static and Eigenvalue Problems

Peng, Chao[1,2]; Tasora, Alessandro[1]; Mangoni, Dario[1]; Fusai, Dario[1]
[1]University Of Parma; [2]Goldwind Science & Technology Co., Ltd.

The tangent stiffness matrix of constraints arises from the directional changes of reaction forces and torques at the joints. This matrix becomes more relevant in systems comprising extremely soft flexible bodies and is particularly critical in rigid-body systems. Although numerous studies on the linearization of the equations of motion for constrained multibody systems have highlighted the presence of the tangent stiffness matrix of constraints and provided joint-specific expressions, a unified analytical framework for holonomic constraints, including rheonomic components, remains absent. The holonomic constraint equation for lock joints is proposed using quaternion parametrization and is subsequently employed to compute the Jacobian matrix of constraints. A consistent and unified analytical formulation of the tangent stiffness matrix for holonomic constraints is derived based on this parametrization. The developed formulation can be readily applied to a series of inherited common joints by suppressing the corresponding rows in the constraint equation and the Jacobian matrix of constraints. By introducing a shadow frame governed by rheonomic functions, the formulation extends seamlessly to rheonomic constraints. Numerical examples demonstrate that the formulation enhances convergence in static equilibrium analysis, and improves alignment between eigenvalue predictions and oscillation frequencies identified in nonlinear dynamic simulations.

Abstract ID: 108

External Force Observer and Control for a Compliant 2-DOF Manipulator

Aarts, Ronald; Dasdemir, Janset
University of Twente, Enschede, Netherlands

Force or torque control should assure that a manipulator interacts with some predefined force with its environment. In a compliant manipulator the deterministic behaviour of the system can be exploited to estimate this interaction force without a force sensor. In the paper we use a multibody model of a 2-DOF manipulator with flexure joints of which the physical parameters have been experimentally identified. It is shown that this model can be implemented quite straightforwardly in a force control system to apply a constant force on the environment while the end-effector is moving in both directions.

Abstract ID: 109

An Automatic-Differentiation-Based Approach to Simulation of Flexible Multibody Aircraft

Preston, Ben[1]; Palacios, Rafael[1]; Fasel, Urban[1]; Castrichini, Andrea[2]
[1]Imperial College London; [2]Airbus Operations Ltd.

A framework for the simulation of flexible multibody aircraft is presented. A suitable nonlinear flexible multibody formulation is developed, which is general for holonomic and nonholonomic constraints. The constraint functions are written using automatic differentiable primitive functions within the Google JAX framework, allowing for the Jacobians of Python function to be determined, which are required in the solution process. This give a simple and interpretable approach to the implementation of constraints, particularly when the Jacobians prove to be nontrivial to derive. This is used for the simulation of free or actuated rotations between bodies, which when coupled with unsteady vortex lattice method aerodynamics, gives a general nonlinear aeroelastic analysis tool to investigate the dynamics of flexible aircraft with multibody wingtips. Analysis for a range of multibody flexible aircraft is presented, with a variety of scenarios used to investigate their performance. The work presented has been implemented into the aeroelastic analysis package SHARPy, developed at Imperial.

Abstract ID: 110

Anderson-Accelerated Fixed-Point Method for Solving Multibody Problems with Constraints and Contacts

Fusai, Dario; Tasora, Alessandro; Mangoni, Dario; Peng, Chao
University of Parma, Italy

We propose an Anderson-accelerated (AA) method for the efficient solution of multibody problems involving large amounts of hard frictional contacts and bilateral constraints. The method is rooted on a fixed-point iteration as a way to solve the underlying complementarity problem arising from the differential-variational-inequality (DVI) formulation of non-smooth dynamics. By leveraging AA we are able to increase the convergence rate of conventional schemes – e.g. projected Gauss-Seidel or projected SOR – up to the performance of state-of-the-art Krylov solvers.

Abstract ID: 111

A Novel Implicit Non-Smooth Formulation for Peridynamics with Dual Variables

Tasora, Alessandro; Mangoni, Dario; Fusai, Dario
University of Parma, Italy

This work presents an original approach to the implicit time integration of deformable materials based on the peridynamics formulation. Adding peridynamics to multibody tools permits a versatile treatment of problems involving large deformations, plasticity and fracture. We experienced that, restricting the attention to bond-based peridynamics models, bond forces can be represented as constraints in a DAE, where compliance is added to the algebraic equations. We call them horizon-constraints. These constraints lead to some useful consequences. First, there is no need of building tangent stiffness matrices for the Newton iterations in implicit integrators, because the same effect is obtained using the very simple jacobians of the horizon-constraints in a saddle-point problem, where the dual

variables are the bond forces. Secondly, the same constraints can be used in the framework of Differential Variational Inequalities (DVI), that is in non-smooth formulations: in this case they are promoted to complementarity constraints and are able to represent contacts between peridynamic particles in a more robust end efficient way than usually done in the field of conventional peridynamics, that usually deals with contact using repulsive force fields.

Abstract ID: 112

Approximating the Inertia Forces in the Floating Frame Formulation Using Finite Elements with Rotational Degrees of Freedom

Van Voorthuizen, Karlijn; Abdul Rasheed, Mohammed Iqbal; Schilder, Jurnan; Ellenbroek, Marcel
University of Twente, Netherlands, The

The inertia forces in the floating frame formulation contain volume integrals that depend on the degrees of freedom of the formulation. These volume integrals are often expressed in terms of the inertia shape integrals, which are time-independent. However, doing so requires complex summation operations, making its implementation prone to mistakes. When modeling elements that are invariant to rotations, all volume integrals in the inertia forces can be written in terms of the consistent finite element mass matrix. However, for elements with rotational degrees of freedom, approximations are required to achieve this. In this work, an approximation of the inertia forces is derived which is straight forward to implement as no other volume integrals appear but the consistent finite element mass matrix, and which is applicable for elements with both translational and rotational degrees of freedom. The approximations involved in obtaining this definition for the inertia forces and its accuracy are discussed in the presentation.

Abstract ID: 113

Distributed Hybrid Test of Wind Turbine Pitch Bearing

Kristiansen, Frederik Nordtorp[1]; Baş, Elif Ecem[2]; Jensen, Per Baunegaard With[4]; Jørgensen, Jan[4]; Gomes, Cláudio Ângelo Gonçalves[3]; Abbiati, Giuseppe[1]
[1]Aarhus University, Denmark; [2]R&D Test Systems A/S, Hinnerup, Denmark; [3]Department of Electrical and Computer Engineering, Aarhus University, Denmark; [4]FORCE Technology, Park Allé 345, 2605 Brøndby, Denmark

Hybrid testing is emerging as a key enabling technology for developing increasingly larger wind turbine mechanical components. In a typical setting, a physical experiment is coupled with a numerical model in a closed loop to reproduce system-level dynamics. However, in a competitive wind market that chases reckless growth in size and power, original equipment manufacturers are reluctant to share computational models and grant access to experimental facilities. In response to this challenge, the DLTE project, funded by the Danish Department of Energy, has developed a platform for geographically distributed hybrid testing. The platform utilizes FMI-based distributed co-simulation to combine physical and numerical models. Communication is enabled by an Azure cloud service. This contribution provides an overview of the experimental proof-of-concept recently demonstrated at the Force Technology, Lindø Component and Structural Testing Facility. The lesson learned is that geographically distributed testing is feasible, secure, and robust but not suitable for real-time. Moreover, the Kane method is very efficient in coupling physical and numerical models in a multi-body dynamical setting.

Abstract ID: 114

Coupled Simulation of Steady Helicopter Forward Flight for Vibration Analyses

Frie, Lennart[1]; Wengrzyn, Oskar[2]; Keßler, Manuel[2]; Eberhard, Peter[1]
[1]Institute of Engineering and Computational Mechanics, University of Stuttgart, Germany; [2]Institute of Aerodynamics and Gas Dynamics, University of Stuttgart, Germany

Helicopters are highly versatile yet complex multibody systems, often prone to vibrations that can affect onboard comfort and operational efficiency. Addressing these challenges at a late stage of development significantly increases costs, making early simulation-based vibration predictions crucial. Accurate vibration prediction requires capturing the interactions between structural dynamics and aerodynamics through coupled simulations. This work advances helicopter vibration analysis by coupling the aeromechanics solver CAMRADII with high-fidelity computational fluid dynamics (CFD) and utilizing highly accurate reduced-order models for airframe deformations. These models improve upon the modally reduced models used in earlier studies. The study compares two coupling approaches: one-sided, where aerodynamic forces are applied but structural feedback is neglected, and two-sided, which incorporates reciprocal interactions between structural displacements and the flow field. The results demonstrate the general applicability of the framework for simulating complex helicopter dynamics. Both coupling methods provide realistic vibration predictions, highlighting the dominant blade passage frequency. The reduced-order models achieve high accuracy, confirming their suitability for coupled simulations. This novel framework marks a significant step toward efficient and precise helicopter vibration analysis, offering deeper insights into aeromechanical interactions and paving the way for cost-effective design optimizations.

Abstract ID: 116

A New Method for the Calculation of Contact Forces in the Non-Smooth Dynamics Approach

Sánchez, Eliana Selen; Cavalieri, Federico Jose; Cardona, Alberto
CIMEC, Universidad Nacional del Litoral-CONICET, Santa Fe, Argentine Republic

A wide range of formulations for calculating contact forces has been proposed by various authors, most of which are based on smooth contact models derived from Hertz's law. However, these models often require relatively long computation times due to the small time steps needed for accuracy. In contrast, non-smooth techniques allow for larger time steps, improving computation efficiency. Nevertheless, non-smooth approaches lack a direct method for determining contact forces. This work presents a new methodology that combines non-smooth and smooth contact models to calculate contact forces effectively. The numerical validation example demonstrates that the contact forces obtained align with those from smooth contact models, while achieving a significant reduction in computation time.

Abstract ID: 118

Efficient Multi-Body Dynamics Analysis Using a Data-Driven Component Meta-Model for Flexible Bodies

Choi, Juhwan[1]; Jang, Kyungchun[1]; Kim, Seongsu[1]; Choi, Jin Hwan[2]
[1]FunctionBay, Inc., Korea, Republic of (South Korea); [2]Kyunghee University, Korea, Republic of (South Korea)

Traditionally, Multi-Body Dynamics (MBD) has been used to study interactions between rigid bodies. The integration of Finite Element Analysis (FEA) has expanded this field into Multi-Flexible-Body Dynamics (MFBD), enabling the analysis of deformations in flexible bodies. This enhancement has made MFBD a robust tool for examining complex systems comprising both rigid and flexible components, particularly benefiting Digital Twin (DT) applications by transforming real-world systems into comprehensive digital models. Realizing DT's full potential requires real-time analysis of these complex systems, but current technologies struggle with the challenges posed by high nonlinearity and numerous degrees of freedom. These issues highlight the need for dynamic analysis software to develop faster and more reliable methods for evaluating MFBD systems. Traditional approaches often depend on governing equations, which can be limited in speed and adaptability. Consequently, there is increasing interest in adopting data-driven analysis techniques leveraging machine learning and artificial intelligence to enhance performance and flexibility. This study introduces the Data-Integrated Model-Driven Simulation (DIMDS) approach, combining traditional motion equations with data-driven methodologies to enable faster and more efficient MFBD model analysis, thereby broadening their application across various domains.

Abstract ID: 119

Design of a Generic Chrono Framework for Fluid-Solid Interaction

Serban, Radu; Bakke, Luning; Unjhawala, Huzaifa; Negrut, Dan
University of Wisconsin-Madison, United States of America

FSI problems are ubiquitous. Examples include vehicle mobility (fording operations, liquid sloshing, interaction with deformable terrain) and offshore energy applications (wave and tidal energy converters, offshore wind, etc.). Chrono has provided FSI support for a long time, through a module implementing a CUDA SPH solver. The Chrono::FSI module provides support for solving both incompressible Navier-Stokes equations, as well as continuity and momentum equations describing homogenized granular dynamics used to model deformable soil. Interest in Offshore Energy Systems has motivated a refactoring of Chrono::FSI aiming at: (i) separating the interface between the multibody solver and a fluid solver; (ii) redesigning the Chrono SPH solver to seamlessly support different equations of motion; (iii) enhancing accuracy, robustness, and performance; (iv) extending the FSI interface to improve its modeling, visualization, and post-processing capabilities. This contribution describes the structure of the new generic interface between a Chrono solid-phase multibody system and an arbitrary fluid solver, as well as the integration of the existing SPH fluid solver in this framework. We provide a summary of new developments and enhancements and integration in the Chrono co-simulation framework for vehicle-terrain interaction. We conclude with examples ranging from off-road vehicle mobility to marine wave energy-harvesting devices.

Abstract ID: 120

Functional Mock-Up Interface Support in Chrono

Serban, Radu[1]; Mangoni, Dario[2]
[1]University of Wisconsin-Madison, United States of America; [2]Universita degli Studi di Parma, Italy

Adoption of a standardized co-simulation model exchange interface offers several advantages, including "one-time only" code development for model encapsulation, access to existing or future subsystem models with no changes to the co-simulation framework, and access to proprietary models and libraries. While there are several attempts at providing standard interfaces for model coupling and model exchange, the Functional Mock-up Interface is arguably the standard with the largest user base, advocated by a large number of academic, governmental, and commercial entities. For these reasons, we opted to adopt FMI and implement new Chrono::FMI module to provide the necessary functionality to both wrap Chrono models and simulations in so-called Functional Mock-up Units and couple Chrono simulations to FMUs. We target both FMI 2.0 (because of its widespread use) and 3.0 (for new capabilities, useful in creating FMUs for models with large I/O, such as deformable terrain and sensors). This contribution describes the utility general-purpose library fmu_tools, its use in Chrono::FMI, and illustrates the use of Chrono FMUs in vehicle co-simulation as well as coupling external FMUs to Chrono simulations.

Abstract ID: 121

A Co-Simulation Algorithm for the Efficient Real-Time Parallel Solution of Multibody Systems

Fontana, Andrea; Morandini, Marco; Masarati, Pierangelo
Politecnico di Milano, Italy

Co-simulation is broadly used to enhance and broaden the applicability of numerical simulation. Its points of strength are: (i) the possibility to (re)use existing solvers for the simulation of more complex, often interdisciplinary problems, (ii) to parallelize and speed up the solution of larger problems, and (iii) to support the real-time solution of Human-in-the-loop problems. To achieve these capabilities, algorithms must provide adequate algorithmic stability characteristics and scalability.

Abstract ID: 122

Numerical Whirl-Flutter Investigation of a Multibody/Vortex Particle Tiltrotor Model with Frictional Components

De Vita, Paolo[1]; Cassoni, Gianni[1]; Morandini, Marco[1]; Masarati, Pierangelo[1]; Fonte, Federico[2]; Favale, Marco[2]; van't'Hoff, Stefan[3]
[1]Politecnico di Milano, Italy; [2]Leonardo Helicopters; [3]Royal Netherlands Aerospace Centre

This work aims to understand whether and how modeling friction in selected hub and rotor components, observed during the setup of a tiltrotor wind tunnel model for testing, can help interpret its impact on whirl-flutter stability. Whirl-flutter stability identification is usually based on evaluating the evolution of the damping factors of specific aeroelastic modes within the flight envelope. For nonlinear systems, frequency and damping lose their meaning as stability indicators; however, for small perturbations about an equilibrium condition, nonlinear structures' response can often be approximately considered linear. In practice, an excitation of the structure with a targeted harmonic signal tailored for each specific mode is equivalent to a linearization of the system about a specific operating point. Wind-tunnel test results revealed nonlinear behavior in the system when non exactly axial flow produced some gimbal tilting. It is speculated that such phenomenon can be attributed to frictional forces within specific joints. Friction was observed during ground testing prior to the wind tunnel investigation. It could have restrained the rotor from freely gimbaling when in axial flow conditions and produced additional damping when periodically gimbaling away from purely axial flow conditions.

Abstract ID: 123

Design of a 3-DOF Spatial Manipulator: Torque Minimization for Static and Dynamic Modes

Chesnot, Arthur[1,2]; Arakelian, Vigen[1,2]
[1]INSA Rennes, France; [2]LS2N/ECN, Nantes, France

Minimizing robots' energy consumption is essential to address environmental and economic challenges. This can be achieved by optimizing the mechanism's architecture and components to lower motor torques. Static balancing approaches, such as the redistribution of moving masses with counterweights, are effective but face limitations in dynamic regimes, particularly during high-speed movements. This study introduces a novel 3-DOF manipulator inspired by the Scott-Russell mechanism, with an optimum design both in static and dynamic operating modes. In static mode, a single counterweight redistributes its moving masses so that the system's center of mass moves along a straight horizontal path. This maintains a constant potential energy in the system, consequently leading to the cancellation of the input torques. Then, in dynamic mode, an optimal design approach is proposed. By carefully selecting the parameters of the specified counterweight, the input torques are minimized for Pick-and-Place trajectories with a Bang-Bang control law. This design approach reduces energy consumption and minimizes peak torque during dynamic operation. The results clearly demonstrate the transition between static and dynamic modes, along with a significant reduction in the manipulator's input torques. The method is adaptable to other applications, offering an optimal solution to maximize the energy performance of manipulators.

Abstract ID: 124

Formulating Finite Elements for Flexible Multibody Dynamics Using Plane-Based Geometric Algebra

Bauchau, Olivier
University of Maryland, United States of America

This paper will present the finite element implementation of structural elements typically found in flexible multibody dynamics analysis tools. Throughout the formulation, the kinematics of the system is represented using geometric algebra. First, the formulation of each structural element is developed within the formalism of geometric algebra. Second, the governing equations for each structural ele-

ment are expressed in terms of geometric algebra operations only. Finally, the finite element method in time is used to discretize the various elements in space and time simultaneously. It will be shown that the interpolation of motion is handled elegantly by the geometric algebra formalism. A flexible multibody dynamics analysis tool based on the geometric algebra formalism will be presented and its predictions will be compared with those of more traditional analysis methods. In all cases, excellent correlation is observed. Clearly, geometric algebra is an ideal formalism for the description of the kinematics of flexible multibody systems, the derivation of the governing equations, and their finite element implementation.

Abstract ID: 125

Historical Evolution of Heavy Machinery and Role of Multibody Dynamics

Jaiswal, Suraj[1,2]; Poursina, Mohammad[1]
[1]University of Agder, Norway; [2]Lappeenranta University of Technology, Finland

Heavy machinery has come a long way from the ancient Roman cranes to modern computerized machinery, such as tractors and excavators. In the last century and a half, heavy machinery has evolved significantly with improved productivity, efficiency, and safety. Most technological advances in heavy machinery have been made in the late 1900s and 2000s. Among various factors, multibody dynamics has significantly advanced the development of heavy machinery, particularly after the introduction of computers that enabled the complete characterization of multibody dynamics. The objective of this study is to introduce the historical evolution of heavy machinery and to analyze the role of multibody dynamic simulation in this evolution. The novel contribution of this study is to identify and analyze the contribution of multibody simulation in the evolution of heavy machinery. To this end, the historical evolution of heavy machinery is presented from the ancient times of 30–20 BC to the modern innovations of 2024. The role of multibody dynamics in the study of heavy machinery is divided into five phases, from offering basic analytical models to advanced real-time simulation and automation, integrating multiple disciplines and practical scenarios. The outcome of this study can serve as a benchmark for future work.

Abstract ID: 128

Dynamic Analysis of a Rotating Mindlin Plate Based on Cell-Based Smoothed Finite Element Method

Du, Chaofan[1]; Xu, Ningning[1]; Yu, Chuanbin[1]; LI, Liang[2]; Zhang, Dingguo[2]
[1]Yangzhou University, China, People's Republic of; [2]Nanjing University of Science and Technology

A cell-based smoothed finite element method (CS-FEM) for dynamic analysis of a rotating Mindlin plate is studied in this paper. Considering the high-order terms of non-linear coupling deformation which means the in-plane longitudinal shortening terms caused by transverse deformation, the high-order rigid-flexible coupled (HOC) dynamic model of a rotating hub-plate system based on the first-order shear deformation theory is established via employing Lagrange's equations of the second kind. The 3-node triangular elements is used to discretize the deformation field of the plate and the shear locking issue is eliminated by the discrete shear gap (DSG) method. The simulation results are compared with those obtained by using first-order approximation coupled (FOAC) dynamic model and zero-order approximation coupled (ZOAC) dynamic model, which shows the HOC dynamic model possesses higher accuracy and wider application scope. The results of CS-FEM are also compared

with those other existing methods including the finite element method (FEM) and the assumed modes method (AMM). It is demonstrated that the CS-FEM has better computational stability under the same computational conditions.

Abstract ID: 130

Simulation and Experimental Validation of a Flexible 5-Bar Parallel Robot

Babut, Alexis[1]; Boudon, Benjamin[1]; Guigon, Louis[1]; Bouzgarrou, Chedli[1]; Gagnol, Vincent[1]; Hoang, Nguyen Quang[2]
[1]Université Clermont Auvergne, France; [2]Hanoi University of Science and Technology, Vietnam

This study presents a dynamic model of a flexible 5-bar parallel robot, adapted from the method proposed by Hoang et al. (2022), and validated through experimental tests on a prototype. The model incorporates flexibility using shape functions, similar to the finite element method, to approximate the deformation of elastic links. The differential equations of motion are established by combining the substructure method and the Lagrange equation of the second kind for the serial multibody system. All four bars of the robot are considered flexible in the model, with flexibility accounted for in both transverse and angular displacements. A simulation framework in Simulink is employed to model the robot's mechanical, electrical, and control systems. Experimental validation compares simulation results with real system data, focusing on the end effector's trajectory, angular positions, speeds, and accelerations, measured using sensors such as accelerometers, current sensors, and absolute encoders. The results demonstrate that considering flexibility improves dynamic prediction accuracy over rigid-body models.

Abstract ID: 131

Interface Models for the Simulation of Mechanical Clearances

González, Francisco; Rodríguez, Antonio J.; Sanjurjo, Emilio; Naya, Miguel Ángel
Universidade da Coruña, Spain

Joint clearances give rise to impacts and intermittent contacts. The forward-dynamics simulation of these phenomena requires the use of small integration step-sizes, which increases the time elapsed in computations. Reduced interface models can be used to alleviate this issue. For small clearances, the overall system configuration and velocity can be evaluated with an ideal multibody model with perfect joints. The effective dynamics of the ideal system can then be expressed in terms of the relative motion allowed by the clearance and used to build a reduced interface model, that requires less computational effort to solve and can be integrated at the rate required by the contact phenomena at the interface.

Abstract ID: 132

A Novel Eulerian Newmark Scheme for Cosserat Beams

Cammarata, Alessandro; Greco, Leopoldo; Castello, Domenico; Cuomo, Massimo
Università di Catania, Italy, Dipartimento di Ingegneria Civile e Architettura

The update procedure for an implicit time scheme integrator relies on linear operations involving vectors defined at different time instants. When dealing with rotational coordinates, these vectors belong to different tangent spaces of the SO(3) manifold. This discrepancy makes the process formally in-

consistent with the manifold. A correct implementation should transport all vectors onto the same tangent space. The spherical Bézier interpolation for Cosserat rods, proposed by the authors in [greco2024objective], addresses these issues and provides a generalization to higher-order interpolation of Crisfield's generalized basis functions, ensuring consistency with SO(3). Spin is interpolated using local basis functions that are updated dynamically during motion, adapting to the configuration. This approach enables an Eulerian update of local spin vectors. This work further extends the high-order spherical linear interpolation to derive angular velocity and acceleration fields using De Casteljau's algorithm. The proposed methodology is applied to nonlinear spatial Cosserat rods dynamics, implemented through an Eulerian Newmark scheme with a multiplicative update of rotations. Finally, numerical applications demonstrate the feasibility of the method and its consistency with results reported in the literature.

Abstract ID: 134

Investigations on Hardware Acceleration for Embedded Simulation of Multibody Dynamics

Kargl, Arnim; Eberhard, Peter
Institute of Engineering and Computational Mechanics, University of Stuttgart, Germany

The simulation of multibody dynamics is a fundamental task in many applications, e.g., digital twins for human-machine interaction or model-based control. Especially when deployed to embedded hardware with restricted resources, this task can quickly become a bottleneck in real-time systems. Recent research studies provide helpful insight and results using graphics processing units (GPUs) for multibody computations. However, GPUs are at the current time still rarely used in embedded systems. This motivates investigating if and how hardware acceleration of multibody dynamics simulation, based on the projected Newton-Euler equations, can be achieved using the AMD Zynq 7000 chip family. The Zynq 7000 architecture, combines a powerful microprocessor and a field programmable gate array (FPGA) in a single chip, providing a flexible environment for hardware acceleration. Throughout the work it is studied how a hardware accelerator can be designed and deployed using the AMD high level synthesis tool chain, from the perspective of a mechanical engineer. Preliminary results show, that computing the projection step of the projected Newton-Euler equations on the FPGA can already speed up the numerical integration by about 20 %.

Abstract ID: 135

An Interactive Design Assistant for the Synthesis of Four-Bar Linkages Using a Dual-Network Approach

Röder, Benedict[1]; Eberhard, Peter[1]; Ebel, Henrik[2]
[1]University of Stuttgart, Institute of Engineering and Computational Mechanics, Germany; [2]LUT University, Finland

Designing specialized mechanisms for repetitive tasks offers advantages over general-purpose robots, such as improved energy efficiency, cheaper hardware and reduced wear. However, mechanism design is a time- intensive and experience-driven procedure and remains a challenging task for complex mechanisms. Recent advancements in machine learning have shown promise in aiding this process.

This paper focuses on the data-driven design of four-bar linkages. We propose a dual-network approach inspired by the autoencoder architecture, trained in two phases to overcome the challenges of a multimodal multimodal solution space. The decoder learns forward kinematics, while the encoder predicts mechanism parameters from coupler paths, using a feature-based loss function to handle solution ambiguity. The method outperforms naive neural networks and achieves comparable results to intermediate stages of global optimization approaches, with significantly faster execution times. Additionally, predictions can serve as initial seeds for a local post-optimization, further refining results. We showcase an interactive GUI tool leveraging the trained model, enabling non-experts to design and prototype mechanisms quickly. This approach promises to streamline mechanism design, reducing prototyping time and broadening accessibility in the manufacturing processes.

Abstract ID: 136

Designing a Conditional Obstacle Avoidance for Tracked Vehicles Using Project Chrono and a Neural Network Classifier

Shimada, Shunya[1]; Zhang, Harry[2]; Negrut, Dan[2]
[1]Komatsu Ltd., Japan; [2]University of Wisconsin - Madison, USA

The objectives of this study are: 1) Create simulation pipelines for the development of autonomous operation algorithms for tracked vehicles; and 2) Design the autonomous operation algorithms using these simulation pipelines, which we called–“conditional obstacle avoidance for autonomous tracked vehicle operation”. The high-level vision for the design of a “conditional obstacle avoidance for tracked vehicle” is a) The vehicle continues to follow the reference trajectory when it detects small obstacles that are not needed to avoid; and b) The vehicle avoids the obstacles and returns to the reference trajectory after avoiding it when it detects large obstacles. A neural network is used for identifying hazardous situations. The simulation engine utilized in this study is Chrono, a physics-based simulator platform that supports high-fidelity simulations of vehicles, terramechanics, and sensors.

Abstract ID: 137

Enhancing Time- And Energy Efficiency by Partially Unconstrained Object Manipulation

Zauner, Klaus; Gattringer, Hubert; Müller, Andreas
Johannes Kepler University Linz, Austria

For pick-and-place tasks it is usually aimed to reduce the time required to complete a task. If it is not required to precisely position the object at the target location, the path to be traversed can be divided into two distinct phases: a robot-guided phase and an unconstrained or free-flight phase. For a given target point, a set of release points and related velocities exists, constrained only by the manipulators' task space and dynamic capabilities. Consequently, a multistage approach, comprising the determination of the throwing point and velocity and subsequent planning of the respective acceleration and deceleration trajectories, represents a potential solution to the problem. However, this approach may not be applicable in the presence of task space obstacles. The corresponding consideration of this issue constitutes the focus of this work.

Abstract ID: 138

A Scaled Boundary-Finite Cell Approach for 2D Contact Dynamics with Large Deformations and Complex Interfaces

Feng, Yue; Wang, Kun; Tian, Qiang; Hu, Haiyan
Beijing Institute of Technology, People's Republic of China

In order to efficiently simulate contact dynamics problems with flexible bodies subject to large deformation and complex contact interfaces, a scaled boundary-finite cell approach is proposed. Based on quadtree decomposition algorithms, the embedded material domain can be meshed by a regular Cartesian grid. The key idea is to treat each physical cell as a scaled boundary polygon element, while all boundary cells are computed by employing the finite cell method. The proposed approach not only avoids generating complex boundary-conforming meshes but also reduces the dimension of dynamic equations. Several benchmark examples are used to validate the proposed approach.

Abstract ID: 139

The Effects of Muscle Model and Calibration Strategy on Muscle Fatigue Estimation

Michaud, Florian[1]; Beron, Santiago[1]; Lugrís, Urbano[1]; Márquez, Gonzalo[2]; Cuadrado, Javier[1]
[1]Laboratory of Mechanical Engineering, Campus Industrial de Ferrol, CITENI, Universidade da Coruña, Spain; [2]Group of Learning and Control of Human Movement in Physical Activity and Sport, Faculty of Sport Sciences and Physical Education, Universidade da Coruña, Spain

The determination of muscle forces through computer modeling and simulation is of great interest for estimating loads on bones and joints, with applications in rehabilitation, injury prevention in sports and workplaces, and surgical planning for reconstructing diseased joints. Muscle force capabilities change dynamically over time due to mechanical and physiological variations, such as moment arms, tendon lengths, muscle activation patterns, and muscle fatigue, making their modeling particularly challenging. These parameters are subject-specific and require careful calibration to achieve accurate estimations. Furthermore, more complex muscle models demand the calibration of a greater number of parameters. Since the estimation of muscle fatigue is directly tied to the forces produced by muscles, and the authors aimed to improve their previous results in estimating dynamic activities, the objective of this work is to determine the effect of using different muscle models and calibration strategies to estimate muscle fatigue during short-duration, high-intensity exercises.

Abstract ID: 140

Physics-Inspired Data-Driven Modeling of Complex Mechanical Components for Integration in Multibody Dynamic Simulations

Vanpaemel, Simon[1,4,5]; Kutz, J. Nathan[2,4]; Brunton, Steven L.[3,4]
[1]Department of Mechanical Engineering, KU Leuven, Belgium; [2]Department of Applied Mathematics and Electrical Engineering, University of Washington, United States of America; [3]Department of Mechanical Engineering, University of Washington, United States of America; [4]AI Institute in Dynamic Systems, United States of America; [5]Flanders Make @ KU Leuven, Belgium

This work introduces a physics-inspired data-driven approach for modeling complex nonlinear components in mechatronic systems, such as bushings and shock dampers, which significantly influence overall system behavior. Traditional first-principle models face challenges in balancing accuracy and efficiency, while purely data-driven methods often lack robustness, interpretability, and generalizability. The proposed method integrates Gated Recurrent Units (GRU) to approximate ordinary differential equations (ODEs) and deep feedforward neural networks (FFNN) for measurement equations. Symbolic regression (PySR) is employed to extract interpretable expressions from the trained networks, yielding a complete symbolic representation resembling first-principle-based models. This structure enhances compatibility with multibody simulation solvers and their variable-timestep approaches. The methodology is validated using both simulated and real-world datasets, including a nonlinear spring-damper system and a rubber bushing. Results demonstrate the approach's ability to find a nonlinear map between the latent GRU states and the states obtained by the first-principle ODEs. Furthermore, the approach illustrates that accurate dynamic predictions are possible. The framework's generic nature enables modeling diverse dynamic components with limited input-output data, offering a straightforward and interpretable solution for integrating complex dynamics into multibody simulations.

Abstract ID: 142

Hybrid Contact Force Model Based on FrD2 Dynamic Friction Model

Schuderer, Matthias; Rill, Georg; Schulz, Carsten; Schaeffer, Thomas
OTH Regensburg, Germany

This paper presents a hybrid contact force model for 2D contact problems. This model combines the FrD2 dynamic friction model with a penalty-based normal force model for multibody dynamics applications. The FrD2 model, a second-order bristle-based friction model, accurately reproduces friction phenomena such as stiction and stick-slip. The hybrid model integrates friction and normal contact forces, allowing analysis of complex interactions such as the falling ladder problem. The falling ladder, a statically indeterminate system, is simulated with the FrD2 model, which provides realistic friction forces during equilibrium and dynamic scenarios. Simulations demonstrate the ability of the hybrid model to handle lift-off and impact events, providing improved realism over standard friction models.

Abstract ID: 143

Spatial Distribution of Control Loads to Stabilize an Unconstrained Multibody Simulation

Bolk, Johannes; Corves, Burkhard
Institute of Mechanism Theory, Machine Dynamics and Robotics RWTH Aachen University

For semianalytical simulation methods, loads at the system boundaries are measured during operation and applied in a subsequent multibody simulation to excite the system. With the replacement of the constraints with active loads, instabilities occure as unwanted movements of the model during simulation.A possible solution to reduce the influence of these instabilities is the usage of a control system that calculates a control force vector F and a control torque vector T that counteract the unwanted movement of the unconstrained system. This paper provides an analytical method to distribute control loads on any number of points for special load cases and an unconstrained system in six degrees of freedom. The results have shown that the algorithm provides a homogeneous distribution of the control loads with a minimal sum of the individual forces.

Abstract ID: 144

Optimization of a Compliant Remote Center of Motion Using Distributed Compliant Mechanisms

Zhang, Zhaowei[1,2]; Pieber, Michael[3]; Gerstmayr, Johannes[3]
[1]State Key Laboratory of Robotics; [2]Shenyang Institute of Automation; [3]University of Innsbruck

This work presents an approach to utilizing distributed compliant mechanisms to realize a compliant remote center of motion (RCM). A critical design feature for achieving precise motion control in modular robotics systems. Usually, compliant RCM mechanisms use a linkage-based design with flexure hinges to achieve relative motion. Compliant mechanisms eliminate the size limitations associated with discrete components and remove the need for clearances. However, it is still an open question to design a distributed compliant RCM mechanism using flexural beams. Addressing this point, this paper introduces a two-step optimization approach. Using this method, we identify four distinct topologies and design four detailed distributed compliant RCM mechanisms.

Abstract ID: 146

A Compliant Control Strategy for On-Orbit Assembly of Multi-Interface Modules Based on Residual Reinforcement Learning Compensation

Yan, Xinle[1]; Shi, Lingling[1]; Shan, Minghe[2]
[1]School of Mechanical Engineering, Beijing Institute of Technology, China; [2]School of Aerospace Engineering, Beijing Institute of Technology, China

On-orbit robotic assembly of space structures is among the most promising approaches for constructing large spacecraft. However, the complex and dynamically changing space environment poses significant challenges for the compliant docking of modular units and the construction of space structures. This paper introduces an on-orbit multi-interface compliant control method for robots, leveraging residual reinforcement learning. The proposed method integrates traditional impedance control strategies with a residual reinforcement learning approach based on MVE-DDPG. The impedance control strategy provides guidance for the reinforcement learning training process, thereby enhanc-

ing training efficiency. Multi-interface docking experiments conducted in a simulation environment demonstrate the excellent compliance performance of the proposed method. Furthermore, an experiment platform was developed to validate the practical effectiveness of the approach.

Abstract ID: 147

Real-Time Virtual Sensor System with Finite Element Model-Driven Digital Twin: Theory, Application and Potentials

Kim, Jin-Gyun; Baek, Hyunwoo; Lee, Ji-won
Kyung Hee University, Korea, Republic of (South Korea)

It becomes essential to collect large amounts of quantitative and highly qualitative data. In a real engineering environment, there are a lot of difficulties: (1) limitation of sensor attachment, (2) limitation of the number of sensors, (3) measurement noise cancellation, etc. A virtual sensor is a robust way to reinforce unmeasured data that is difficult to obtain experimentally. The digital twin then plays a key part in the virtual sensing framework to replicate highly accurate data. In this presentation, a real time virtual sensing framework with physics-driven digital twin is introduced. Finite element (FE) model updating and its reduced order modeling are used to define the accurate and efficient digital twin. Input sources, which are external forces or heat flux depending on certain problems, are also indirectly defined by using inverse source identification. Then, utilizing the digital twin model and estimated input sources, other desirable but unmeasured data can be replicated. It can be effectively achieved by using the proposed virtual sensing framework connected to real experimental test beds. Various virtual sensors, which are structural vibration, vibro-acoustics and heat transfer, along with the theories and applications are covered in this presentation.

Abstract ID: 148

Calculation of the Design Horizontal Geometry of a Railway Track Using Inertial Sensors and GPS Measurements Recorded in Line Vehicles

Rodríguez, Miguel; Urda, Pedro; Escalona, José L.
University of Seville, Spain

This work presents an algorithm to calculate the design horizontal geometry of a railway track from inertial and Global Position System (GPS) measurements recorded with a smartphone during a commercial train trip. The algorithm starts by segmenting and classifying the track into the three possible types of segments: straight, circular and transition, calculating an initial approximation to their geometric parameters using the forward velocity, angular velocity and transverse acceleration of the vehicle. Then, the parameters are optimized by including the information of the trajectory recorded by the GPS. Results from multiple trips along the same track are then combined to erase possible mistaken segments. Finally, the algorithm is tested on an 18 km track of the suburban train line C-5 from Seville (Spain) that connects the stations of San Jerónimo and Villanueva del Ariscal y Olivares. Results provide a good approximation of the track's geometry and an estimation of the uncertainty of the calculated geometric parameters.

Abstract ID: 149

Dimensional Reduction of Geometrically Nonlinear Beams: A Center Manifold Approach

Han, Shilei
Beijing Institute of Technology, China, People's Republic of

This paper presents a novel center manifold-based approach for reducing three-dimensional beam models to one-dimensional models. The reduced one-dimensional models consist of six equilibrium equations for the stress resultants and six constitutive equations that relate the derivatives of rigid-section motions to the stress resultants. The key idea is to recognize that the Saint-Venant solution lies within a twelve-dimensional center manifold. In this approach, the beam's kinematics are decomposed into rigid-section motion and a warping field. The center manifold is parameterized by kinematic variables representing the six rigid-section motions and the six stress resultants on the cross-section. The nonlinear relationship between the warping field and the stress resultants, as well as the beam's nonlinear constitutive relationship, are approximated using polynomial expansions. The polynomial coefficients are determined by solving the invariance equation derived from the center manifold reduction process. By increasing the expansion order, the proposed method captures all nonlinearities present in the three-dimensional model and incorporates them into the one-dimensional beam's nonlinear equilibrium and constitutive equations. Numerical examples demonstrate both the efficiency and accuracy of the approach, which is achieved through the analysis of the reduced one-dimensional beam equations and a two-dimensional cross-section analysis to determine the center manifold.

Abstract ID: 150

Data-Driven Hydrodynamics Model for Prediction of Vehicle-Water Interaction

Yamashita, Hiroki[1]; Harwood, Casey[1]; Martin, Juan Ezequiel[2]; Tison, Nathan[3]; Grunin, Arkady[3]; Jayakumar, Paramsothy[3]; Sugiyama, Hiroyuki[1]
[1]University of Iowa, United States of America; [2]U.S. Army ERDC-CHL, United States of America; [3]U.S. Army GVSC, United States of America

A data-driven hydrodynamics model is proposed to enable quick prediction of vehicle mobility in shallow water, considering the effect of tire-soil interaction. To this end, a high-fidelity coupled vehicle-water interaction model using computational fluid dynamics (CFD) and multibody dynamics (MBD) solvers is developed to characterize the hydrodynamic loads exerted on a vehicle operated in shallow water, and it is used to generate training data for the data-driven hydrodynamics model. To account for the history-dependent hydrodynamic behavior, a Long Short-Term Memory (LSTM) neural network is introduced to incorporate the effects of the historical variation of vehicle motion states as the input to the data-driven model, and it is used to predict hydrodynamic loads online exerted on vehicle components in the MBD mobility simulation. It is demonstrated that the vehicle-water interaction behavior in scenarios not considered in the training data can be predicted using the proposed LSTM data-driven hydrodynamics model. A substantial computational speedup is achieved with the proposed LSTM-MBD vehicle-water interaction model while ensuring accuracy, compared to the computationally expensive high-fidelity coupled CFD-MBD model.

Abstract ID: 151

Dynamic Performance Control of the Folding Process for Large Flexible Deployment System

Gao, Chang; Hu, Chenxuan; Gao, Shuojie; Yu, Haidong
Shanghai Jiao Tong University, People's Republic of China

Flexible deployable systems are widely used in aerospace industry due to their lightweight and compliance. The dynamic performance of the folding process is essential for the deployment system, which is difficult to be controlled due to the strongly nonlinear characteristic. In this paper, a novel optimization method of dynamic performance is presented for flexible deployable systems with nonlinear dynamic equations and optimization objectives. The dynamic state transition function of flexible deployable system is derived, and the mathematical description of the trajectory optimization problem is provided. A conditional recurrent neural network is employed to construct the surrogate model of the dynamic state transition function, thereby addressing the issue of computational efficiency. Furthermore, the basic driving sequences are introduced and the optimized variables are transformed into a set of weighted coefficients, which resolve the numerical discontinuity in the surrogate model. The trajectory optimization algorithm is developed with high computational efficiency and feasibility. In the case study, the deployment dynamic performance of a flexible array system is optimized by the proposed method. The numerical results and experimental data demonstrate that the maximum strain energy of flexible thin plates in the deployment process is effectively decreased.

Abstract ID: 152

The Impact of Manufacturing Inaccuracies and Thermal Expansion on Joint Loads Within Overconstrained Multibody Systems—a Case Study

Wojtyra, Marek; Pękal, Marcin
Warsaw University of Technology, Poland

In analyses of multibody systems, manufacturing inaccuracies or thermal expansion are often omitted. These factors—especially in the case of overconstrained systems—lead to an underestimation of joint loads since non-zero self-equilibrating constraint forces are neglected. Some or all joint reaction forces in an overconstrained system cannot be uniquely calculated by a rigid body model. However, hybrid models (with both rigid and flexible bodies) can be used to find realistic reactions. We show that for overconstrained systems with dimensional inaccuracies due to manufacturing errors or thermal expansion, a criterion based on reactions' uniqueness analysis may be used to check whether or not the alteration of dimensions of a given part will contribute significantly to the increase of internal loads. The case study exploits the spatial parallelogram mechanism—a benchmark system known from several publications. We show that the alteration of dimensions of bodies subjected exclusively to unique reactions does not lead to significant changes in joint reactions. We demonstrate that when a body subjected to non-unique reactions changes its dimensions, large changes in reactions are observed in joints. We point out that joints with unique reactions are not susceptible to significant increases in reactions resulting from manufacturing inaccuracies or thermal loads.

Abstract ID: 153

Real Experiments with Flexible Multibody System Dynamics Parallelization

Valasek, Michael[1]; Sargsyan, Artsrun[2]; Mraz, Ladislav[3]
[1]Czech Technical University in Prague, Faculty of Mechanical Engineering, Czech Republic; [2]ENSEA University, France; [3]Gymnazium Prachatice, Czech Republic

The paper deals with the results of real computational experiments of flexible multibody system dynamics simulation on parallel computers. The most effective methods for the parallel multibody dynamics solution are the ones with the logarithmic complexity usually based on the Divide and Conquer (DAC) algorithm. These methods were extended with several advatanges but the computational time improvement by traditional parallelization based on DAC starts at about 300 bodies in single serial kinematic chain, i.e. for very large multibody systems. Therefore it was investigated the computational complexity of this method applied to moderate size of multibody systems usually solved in current engineering practice. So the key question is how many times can be computa-tional time reduced by parallelization for 10-20 flexible bodies solved on parallel computers with 20-20 processors.

Abstract ID: 154

Parallelization of a Multi-Flexible-Body Framework on Distributed Memory Architectures Using MPI

Mangoni, Dario; Tasora, Alessandro; Fusai, Dario
University of Parma, Italy

In this work we present a framework for the parallelization of multi-flexible-body simulations on distributed-memory architectures based on Message Passing Interface (MPI). The proposed solution is designed to address a broad class of systems with variable topology, such as those arising from multibody dynamic problems with non-smooth contacts, where not only bodies and finite elements but also constraints, contacts, loads and other items can be transferred between different domains also at runtime. To achieve this, an effective serialization/deserialization scheme is proposed that enables not only to transfer, but also to share objects between different domains. In this paper also two preliminary implementation of specialized solvers are discussed: the first, a straightforward lumped-mass solver for explicit integration; the second, a Projected-SOR solver for implicit solution of non-smooth dynamic problems involving cone complementarity conditions.

Abstract ID: 155

A Strain-Continuous Finite Element Formulation of Geometrically Exact Beam Based on Geometrical Hermite Interpolation

Chen, Ju; Huang, Ziheng; Tian, Qiang
BIT, China

The geometrically exact beam element established on SE(3) Lie group has a natural coupling of the rotational and the translational variables and can further avoids the shear locking of beam elements [1]. The proposed beam element interpolation is a linear interpolation for relative configuration vector on Lie algebra se(3). However, the classic geometrically beam element is C0-continuous, and the convective strains at the beam cross-sections are not well-defined. C1-continuous elements can

better represent the smooth curved contact force than the extensively used C0-continuous elements, which sometimes can benefit to the efficient and robust computation for contact dynamic problems. A novel strain-continuous geometrically exact beam element is proposed. Firstly, the theory of Magnus expansion [2] is introduced to simplify the description of interpolated element stress tensor and strain energy. Then, the idea of the geometrical Hermite interpolation is proposed to avoid complex operators and further reduce geometric nonlinearity greatly. Finally, some numerical examples are used to validate the element's strain-continuity and convergence rate.

Abstract ID: 156

A 3D Soft DEM for Large-Scale Soft Sphere Dynamics Simulations

Li, Zonglin; Tian, Qiang; Chen, Ju; Hu, Haiyan
Beijing Institute of Technology, China, People's Republic of

Soft particles, unlike rigid particles, consist of highly deformable units commonly found in nature, biology, the food industry, the chemical industry and the mechanical engineering. Most existing methods for simulating dynamics of soft particles, such as the combined finite-discrete element method and the smoothed particle hydrodynamics-discrete element method, are computationally expensive because each particle involves thousands of degrees of freedom (DOFs). Consequently, they are limited to problems with thousands of particles in 2D or only hundreds of particles in 3D. This study proposes a 3D soft discrete element method (3D SDEM) for efficient large-scale soft sphere dynamics simulations. The 3D SDEM maintains the accuracy of existing methods, while significantly reducing computational costs, as each sphere requires only 12 DOFs.

Abstract ID: 157

A Frequency-Based Model Order Reduction Scheme for Dynamic Systems

Masoudi, Ramin
American University in Dubai, United Arab Emirates

A frequency-based model order reduction scheme is presented in this paper. The effectiveness of a reduced-order model for nonlinear dynamic systems heavily relies on the training input, which refers to the original input used to generate the system's dynamic response as a basis for the reduction process. As inputs to the system is continuously changing, accuracy of the reduced-order model response might be affected depending on the scale of input signal deviation from the training input. The key idea in this work is to construct a reduced-order system based on a training input containing all the dominant frequencies/frequency ranges that might be applied to the system during its operational life. It helps to involve all the components that contribute dominantly to the response of the nonlinear system for the particular input. The response of the reduced-order model is examined when some of these frequencies are absent in the input to the system. In other words, robustness of the reduction scheme to inputs that are not necessarily the same as the training input is studied.

Abstract ID: 158

Modelling and Identification of Passive Effects in Serial Robot Joints and Their Influence on Control

Zavřel, Jan; Bergrová, Šárka; Šika, Zbyněk
Czech Technical University in Prague, Czech Republic

Friction within robotic joints can be a critical factor that directly influences a robot's performance and efficiency. The friction provides the dissipation forces which can help to stabilize motions during control, however friction often brings undesirable phenomena like a stick-slip effect and generally nonlinear unpredictable forces. Therefore the friction can lead to energy losses, overheating, and control inaccuracy. It is also crucial to set up the correct friction effects model description and identify the values of the model. It can be done by an identification process. The model with the identified values can then be used in the control loop to improve accuracy and power efficiency. Finally, models are used to control the robot and the results are compared. The model of KUKA LBR iiwa 14 R820 was used as a benchmark.

Abstract ID: 159

Discrete Adjoint Gradients for Constraints Using Implicit Time-Integration

Lichtenecker, Daniel[2]; Nachbagauer, Karin[1,3]
[1]University of Applied Sciences Upper Austria, Austria; [2]Technical University of Munich, Germany;
[3]Institute for Advanced Study, Technical University of Munich, Germany

The adjoint variable method and the direct differentiation method are two key approaches used in sensitivity analysis to compute first-order gradients in optimization. Direct differentiation involves a straightforward differentiation of the cost function, constraints, and state equations with respect to the optimization variables. Therefore, this method can become computationally elaborate, particularly for large-scale optimization problems. In contrast, the adjoint variable method computes sensitivities by solving adjoint equations which size do not depend on the number of optimization variables. This approach eliminates the need to directly compute the sensitivity of the state equations and, therefore, significantly reduces the computational cost in sensitivity analysis of large-scale optimization problems. This work presents a discrete version of the adjoint gradient approach for equality and inequality constraints, which can be used for efficient gradient computation in sensitivity analysis or optimization of large-scale problems. The basic approach has been proposed by Lichtenecker and Nachbagauer and is extended in this paper to incorporate implicit one-step time integrators. With this extension, the sensitivity analysis for systems that are solved with implicit time integrators can be computed efficiently.

Abstract ID: 160

Impacts Between Multibody Systems and Deformable Structures

Lipinski, Krzysztof
Gdansk University of Technology, Poland

Collisions and impacts are the principal reasons of impulsive motions, which we frequently see in dynamic responses of systems. Clearances at mechanical joints, gear train backlashes, motion limiters, capturing of objects, ratcheting mechanisms, walking or brachiating robots are some examples. Precise modeling of impacts is a challenging problem due to the lack of the precise and commonly accepted constitutive law that governs their mechanics. To model the impact, two alternative attempts were dominant: the impulse/momentum-balance law (a); constitutive formulas that govern the mechanics of deformations at the small zones of contact, taking place in the short-term interval (b). Both the classical interaction models are insufficient to express energy transfers in all details, e.g., the amount of indicated post-impact vibrations of elastic components.This paper attempts to present a critical look at the problem of modeling impulsive interactions appearing in multibody systems colliding with elastic structures, where the lasts are considered as motionless (apart from the shock-indicated vibrations) and relatively rigid.

Abstract ID: 161

Flexible Multibody Dynamics of the Enterprise Amusement Ride

Roubos, Harmen; Schilder, Jurnan
University of Twente, Netherlands, The

The Enterprise is an amusement ride in which passenger gondolas are freely suspended from a rotating frame that is raised to a near vertical position. In this work, a flexible multibody dynamic model is created in which the rotating frame is considered as a flexible body. The Craig-Bampton method is used to reduce the full finite element model of the frame. This reduced order model is important in a multibody environment in which the entire ride sequence is simulated. Using the floating frame of reference formulation, the large motions of the amusement ride and the small structural deformations of the frame are computed simulatenously. Passenger accelerations and natural frequencies and modes are compared with experimental data. It is found that the influence of the frame flexibility on the motions and g-forces can be ignored. However, the flexible multibody model provides a more realistic computation of the structural deformations of the rotating frame than current industry practice. By means of this flexible multibody dynamics model, assessments of static strengh and fatigue strength can potentially be improved.

Abstract ID: 162

Line-of-Sight Positioning for Dual Stage Gimbal with Non-Orthogonality Imperfections

Rówienicz, Łukasz[1,2]; Malczyk, Paweł[2]
[1]PCO S.A., Poland; [2]Warsaw University of Technology

One of the critical parameters for high-precision stabilized platforms is the ability to accurately determine or set the angular position of the LOS (line-of-sight). Usually, the LOS is expressed as two angles of azimuth and elevation at which the pointing vector of the selected sensor (usually in the middle of its field of view) is oriented. In the 2-axis gimbal platform, these angles can be taken directly from the encoders. This task is much more complicated when we want to set the LOS position in the 4-axis gimbal platform; thus, angle measurements obtained from encoders cannot be directly added because transformation does not commute. Additionally, some other imperfections affect the position of the LOS, such as orthogonality errors from gimbal geometry. The primary contribution of this paper is to demonstrate a method to improve the determination of the LOS angular positions using a cascade position control system that takes azimuth and elevation angles as a reference. The mentioned effects are investigated on a developed multi-body model of a dual-stage platform with four degrees of freedom (DOF) and commented with respect to robustness and control performance.

Abstract ID: 164

A Curvilinear Beam Finite Element for Geometrically Nonlinear Static and Dynamics Analysis of Flexible Multibody Systems

Iandiorio, Christian[1]; Salvini, Pietro[1]; Botta, Fabio[2]; Valentini, Pier Paolo[1]
[1]University of Rome Tor Vergata, Italy; [2]University of Rome Tre

This paper introduces a beam formulation tailored to address the static and dynamic simulation of highly flexible slender bodies. The cornerstone of the proposed approach is its ability to model an entire curvilinear body using a single element, even when significant nonlinearities arise due to large displacements and rotations. Unlike conventional formulations that rely on pre-defined shape functions, the proposed method bypasses this limitation. This feature minimizes the required DOFs to perform the simulation. The internal displacement field is computed directly through the integration of kinematic compatibility equations, eliminating the need for pre-set shape functions. The formulation derives the tangent stiffness and mass matrices by integrating compatibility and equilibrium equations, along with the elastic stiffness and mass properties of the cross-section. These matrices are efficiently computed as a sum of pre-integrated contributions from section-slice subdivisions, which can be evaluated analytically once and reused across iterations. The effectiveness of the method is demonstrated through numerical comparisons, encompassing both static and dynamic simulations benchmarked (e.g. static and dynamics of cantilever beam, swinging flexible pendulum, etc.) against established finite element solutions.

Abstract ID: 166

An Implicit-Implicit Asynchronous Time Integrator for Multibody Systems with Unilateral Constraints

Wang, Kun; Tian, Qiang
Beijing Institute of Technology, China, People's Republic of

Using a monolithic synchronous time integration method to solve large multibody systems with unilateral constraints due to contact and impact is inefficient because nonsmooth behaviours limit the time steps to be very small. Considering the multi-scale dynamics response of the subdomains with and without nonsmooth behaviours, an implicit-implicit asynchronous time integration method is proposed for the multibody system with unilateral constraints. Newmark algorithm with large time steps is used in the subdomain without contact while the Moreau-Θ algorithm with small time steps is employed in the subdomain with contact. Different subdomains are coupled by enforcing the velocity and position continuity simultaneously at the interface at the macro-time step. A hybrid MPI-OpenMP parallel solution procedure is designed to improve the simulation efficiency. The accuracy and efficiency of the proposed method is validated by several numerical examples. Compared to the synchronous method, the parallel HATI method can achieve up to a 56% reduction of computation time for a complex multibody system.

Abstract ID: 167

Identification of Friction in Joints for Multibody Dynamics: An Adjoint-Based ANN Approach

Sun, Guangxin; Ding, Yuxuan; Han, Shilei
Beijing Institute of Technology, China, People's Republic of

Accurate prediction of the dynamic response of multibody systems critically depends on precise modeling of frictions within their joints. Traditional methods rely on preselected friction models with multiple parameters calibrated from experimental results, these approaches are constrained by model and parameter selection. This paper proposes an adjoint-based Artificial Neural Network (ANN) method to identify frictions in joints. By embedding an ANN to represent joint frictional effects, the proposed method eliminates the need for predefined friction models. The ANN takes Lagrange multipliers and relative joint coordinates as inputs, producing friction forces that match the dynamic responses observed in experimental measurements. Furthermore, the embedded ANN incorporates physics-informed knowledge of the joints to efficiently model frictional forces and moments. To enhance computational efficiency, the discrete adjoint method is employed for sensitivity analysis of state variables. Experimental examples involving planar and spatial double pendulum systems with revolute joints and friction are designed to evaluate the robustness of the model. The results reveal that the embedded ANN, enriched with physics-informed knowledge, can reliably identify frictions from noisy experimental data. Additionally, the trained model can predict the dynamic responses of the system from various initial conditions, demonstrating robustness and generalization ability.

Abstract ID: 168

Improving the Vibration Performance of an Artwork Transport Crate

Ziegler, Pascal[1]; Gao, Yulong[1]; Velte, Stefan[2]; Eberhard, Peter[1]
[1]University of Stuttgart, Germany; [2]hasenkamp Internationale Transporte GmbH

Artwork never arrives at its destination in the exact same condition in which it had left a museum. This is partially due to unavoidable hazards, such as fluctuation in temperature, humidity, dust and light, but beyond that, artwork is exposed to mechanical vibration which is very difficult to avoid. Consequently, the demand for professional transportation crates with enhanced vibration isolation has been increasing significantly. This contribution presents the dynamic analysis of a transportation crate and its optimization in terms of vibration isolation. In order to improve the vibration performance a finite element model of the crate, the absorber elements, and the inner wooden frame is presented. To realistically reflect the direction-dependent behavior of wood, an orthotropic material law is used. The finite element model is compared to results from experimental modal analyses to identify the material properties of the wooden frame. The nonlinear behavior of the shock absorbers is linearized around the operation point, and the respective stiffness and viscous damping coefficient are experimentally identified. The experimentally validated model is used to optimize the vibration isolation performance. Considering practical feasibility and cost, three different configurations are identified and their expected improvement is confirmed during a real art transport.

Abstract ID: 169

Reliable and Smooth Haptic Force Feedback in Interactive Multibody Simulations

Cellupica, Alessio; Cirelli, Marco; Valentini, Pier Paolo
Department of Enterprise Engineering, University of Rome Tor Vergata, Italy

Industry 4.0 technologies such as mixed reality requires to focus on the integration of reliable interactive dynamic simulations in virtual environments. They can be used as immersive training tools or as realistic verifications of user-oriented design functionalities. The level of realism can be enhanced by haptic force feedback to the user. In this way, the user can interactively change the boundary conditions of the model, and the model can return the haptic sensations to him. The main problem is the right way to return forces in dynamic mode. Integration into complex structures is difficult and requires an intervention at the modelling level. The aim of this work is to propose a general approach to the construction of a multibody interactive model that allows easy and robust integration with available haptic devices. The methodology is based on the use of "phantom handles" that act as communicators between the virtual model and the haptic device. The haptic forces can be calculated as the bushing forces between these virtual handles and the rest of the model. The methodology has been tested on three test cases. The methodology is general and can be integrated into interactive virtual reality scenarios and into interactive digital twins.

Abstract ID: 170

A Fast Force Gradient Approximation for the Polygonial Contact Model

Grünberger, Jürgen; Steiner, Wolfgang
University of Applied Sciences Upper Austria; Institute of Mechanics and Mechatronics, TU Wien

Recent work has shown that the Polygonal Contact Model (PCM) can accurately capture the complex interactions of real measured tooth geometries when applied to the multibody simulation of gear dynamics. There, each tooth is discretized into tens of thousands of polygons, resulting in highly detailed surface meshes. While this level of detail is crucial for modeling real-world geometry deviations in gear teeth, it poses challenges in maintaining efficient simulations. Implicit time integration methods in multibody simulation ensure stability and handle stiff dynamics with larger time steps. Such methods require the knowledge of the contact force gradients (i.e., the Jacobian of the contact forces with respect to positions and orientations). Traditional finite difference calculations of this Jacobian, however, become extremely costly if each contact force evaluation requires complex contact detection with thousands of polygons. The upcoming work outlines a new gradient approximation approach designed to address this bottleneck.

Abstract ID: 172

Discontinuous Galerkin Method for Flexible Multibody Systems Based on Vectorial Parameterization of Motion

Qi, Yifan; Shan, Minghe; Tian, Qiang
Beijing Institute of Technology, China, People's Republic of

In order to balance larger time step and higher fidelity of simulations of flexible multibody systems, this paper considers variational integration with high order of accuracy. Some scholars have made contributions in the study of high-order time integration methods. Leitz et al. starts from Hamilton's variational principle to derive Lie group variational integrator for flexible beams. Despite its excellent structure preserving ability, it is computationally expensive to calculate the differentiation of velocity. Hamilton's two field formulation has been employed by Han and Bauchauto simplify the inertia terms in high order variational integrator. However, the cost of using two field formulation is solving additional equations used to enforce velocity compatibility relationships. Therefore, it is necessary to develop a high-order integrator with higher computational efficiency. This paper presents a discontinuous Galerkin integrator based on one-field Hamilton's principle. The differentiation of velocity is eliminated by introducing compatibility relationships and test functions. Then vectorial parameterization of motion is exploited to linearize the interpolation of motion and velocity, so as to reduce non-linearity without introducing independent velocity. Finally, the accuracy of the proposed Galerkin integrator is verified through numerical examples.

Abstract ID: 173

Viscoelastic Modally-Reduced Nodal-Based Floating Frame of Reference Formulation

Zwölfer, Andreas; Holzinger, Stefan
Chair of Applied Mechanics, Technical University of Munich, Germany

The floating frame of reference formulation (FFRF) is a widely used and efficient method for analyzing small-deformation flexible multibody systems. The FFRF conventionally relies on finite element (FE) codes to supply the necessary data for calculating the FFRF invariants to ensure independence from lower-level FE capabilities. While many studies focus on elastic components, the analysis of viscoelastic behavior has received limited attention, despite its significance. Existing research primarily addresses beams and shells using geometrically-exact or absolute nodal coordinate formulations, leaving a gap in the literature regarding continuum FE components modeled with FFRF. This contribution bridges this gap by extending the modally-reduced, nodal-based FFRF to incorporate viscoelastic effects. Through a carefully designed modal reduction procedure, the inertia invariants remain unchanged. Furthermore, the conventional elastic forces are replaced by viscoelastic forces; the additional invariants required for the reduced viscoelastic stiffness and damping matrices are clearly defined, and the procedure for exporting them from FE codes is demonstrated, ensuring compatibility with conventional multibody simulation workflows. Despite these changes, the structure of the resulting EOMs remains unchanged, allowing for seamless integration within existing FFRF implementations, as demonstrated using the open-source package Exudyn.

Abstract ID: 174

Eigenvalue Shift Using the Eigenvalue Perturbation

Schulz, Carsten[1]; Graneß, Henry[2]; Weinzierl, Stefan[1]; Nicklas, Johannes[1]
[1]Regensburg University of Applied Sciences, Galgenbergstr. 30, 93053 Regensburg, Germany; [2]Hilti AG, Hiltistraße 2, 86916 Kaufering

The daily work of development engineers in the field of structural mechanics and flexible multibody system dynamics (FMBD) involves calculating the eigenvalues of a system, as these are crucial for avoiding high vibration amplitudes that can cause material fatigue. Engineers try to move the eigenvalues outside the operating range to minimize economic damage and safety risks. The design process begins with digital sketches and CAD models, followed by the application of the finite element method (FEM) or FMBD for eigenvalue analysis. Changes to the geometry require repeated analysis, which is time consuming and highly dependent on the experience of the engineer. The application of perturbation theory to eigenvalue sensitivity analysis offers a promising solution to optimize problematic eigenvalues without affecting the others. The following applies the perturbation theory on three examples: a mechanical drivetrain, an motor control and a machine frame of a wind energy turbine. The implementation of a defined workflow and the development of a user-friendly tool are crucial to make this method accessible to engineers and speed up the design process.

Abstract ID: 175

A Concept of the Metamodel Based on the Dynamics Analysis Results of the Eccentric Crank-Rocker Mechanism

Urbaś, Andrzej; Stadnicki, Jacek
University of Bielsko-Biala, Poland

Crank-rocker mechanisms are often used in different machines, e.g. in textile industry machines to perform the functions of feeding a thread during knitting or to beating up a newly inserted weft during weaving etc. with the help of a rocker. Then, in the initial phase of their design, the dimensions of the mechanism are sought which, at given crank revolutions, will allow obtaining e.g. the maximum kinetic energy of the rocker or the possibly long duration of the so-called pseudo-stop of the rocker – i.e. moving with a very low angular velocity. The phase of a pseudo-stop enables the mechanism with eccentricity with appropriately selected lengths of links. In the next a computational model much more adequate to reality, i.e. taking into account the flexibility of the crank drive and the flexibility of the links in the mechanism joints can be elaborated.

Abstract ID: 176

Model Predictive Pose Optimisation for Energy Efficient Robotic Machining

Carstensen, Philip[1]; Seifried, Robert[2]; Möller, Christian[1]; Böhlmann, Christian[1]
[1]Fraunhofer Institute for Manufacturing Technology and Advanced Materials - IFAM; [2]Institute for Mechanics and Ocean Engineering, Hamburg University of Technology

A major focus of aviation research in recent years has been the reduction of greenhouse gases thanks to weight savings in aircraft construction, e.g. using lightweight materials such as CFRP components. Lower aircraft fuel consumption has an impact on the global carbon footprint and is an important step towards CO2-neutral flying. In order to achieve national climate goals, the environmental impact should already be assessed at the production stage. Most recently, hybrid kinematics consisting of serial kinematics (industrial robot) and parallel kinematics (hexapod) mounted to the robot's end effector, have been studied at Fraunhofer IFAM for the purpose of machining CFRP-components. This work analyses the extent to which the redundant degrees of freedom of such hybrid kinematics can be exploited to determine energetically advantageous poses during machining. Therefore, the inverse kinematics are solved within an Optimal Control Problem (OCP) including the forward kinematics as well as minimizing the system's total energy while following a reference trajectory.

Abstract ID: 179

Online Error Learning for 2DOF Planar Robot Control Using Adjoint Method and Data-Driven Inverse Dynamics

Pikuliński, Maciej; Maciąg, Paweł; Malczyk, Paweł
Institute of Aeronautics and Applied Mechanics, Warsaw University of Technology, Poland

Feedforward control is a widely employed technique in robotics. By leveraging the system's dynamics model, it predicts control signals needed to achieve desired goals. In this work, we adopt an adjoint-based optimal control approach, enabling the feedforward controller to minimize a predefined cost function. Nevertheless, the model underlying the feedforward controller is rarely perfect in practical scenarios. Factors such as unmodeled phenomena, external disturbances, and parameter uncertainties can lead to discrepancies between the predicted and actual system behavior. While PID controllers remain the industry standard to mitigate these challenges, we follow the recent success of data-driven inverse dynamics (DID) in error learning and assisting a neural-network-based feed-forward controller – an approach originating from regression-based techniques and dynamic mode decomposition (DMD). The proposed control structure updates the error model online, enhancing its adaptability. We apply this strategy to control a 2DOF planar robot – a five-bar linkage mechanism with two controllable actuators. This system has been previously studied for modeling using DMD and time-delay embeddings. While earlier works focused on a data-driven approach to model the entire mechanism, we now use a related methodology to assist with error learning of the feedforward controller, which opens up a range of new research questions.

Abstract ID: 180

Dynamic Analysis of Coupled Vibration Instability in Rolling Mill

Arora, Rohit
Mitsubishi Heavy Industries, Japan

Polygon wear of work roll in rolling machine due to self-excited vibration is known phenomenon. However, vibration measurement during actual operation is required to identify natural frequencies of the rolling mill and develop vibration stabilization system. In this work, multibody dynamics (MBD) model of rolling mill is created for rolling mill operating mode estimation that can lead to polygon wear of work roll.

Abstract ID: 183

Vibration Analysis and Electrode Arrangement of Rotating Piezoelectric Laminated Micro-Beams

Liu, Haocheng[1]; Chen, Yuanzhao[2]; Zhang, Dingguo[1]; Guo, Xian[1]; Li, Liang[1]
[1]School of Physics, Nanjing University of Science and Technology, Nanjing, People's Republic of China; [2]School of Mechanical and Automotive Engineering, Guangxi University of Science and Technology, Liuzhou, People's Republic of China.

Rotating piezoelectric laminated micro-beams (RPLMB) is a main component of rotating piezoelectric ener-gy harvesters. For rotating beams, it has been reported that the frequencies (loci) rise as the angular velocity increases. Since the slopes of different order frequencies are different, there would

be frequency loci veer-ing (FLV). FLV and mode shift of RPLMB would be more complex than those of rotating beam with non- micro scale because of size-dependent effect and piezoelectric effect, which has been rarely reported by existing references. This study develops a novel model of RPLMB based on Absolute Nodal Coordinates Formulation (ANCF). The correctness of this model is verified by comparison with the result in the extant literature. The results show that FLV and mode shift strengthen amplitudes of vibration and voltage as com-pared to the cases without FLV and mode shift. The angular velocities of FLV are affected by ratio of height to material length scale parameter and ratio of radius to length. Moreover, Electrode arrangement can be optimized according to curvature distribution, and then the output voltages for the 2nd to the 4th order vibrations rise by more than 70%, 120% and 180%.

Abstract ID: 185

Use of the Transfer Function of Rail Irregularity to Wheel Acceleration for Track Geometry Inspection

Escalona, José[1]; Yu, Xinxin[2]; Muñoz, Sergio[1]; Urda, Pedro[1]; Aceituno, Javier[3]; Rodríguez, Miguel[1]
[1]Universidad de Sevilla, Spain; [2]Tampere University, Finiland; [3]Universidad de Jaén, Spain

This investigation uses a scale vehicle-track experimental facility to study the calculation of rail corrugation using vertical accelerations measured in the axle-box of rail vehicles and a transfer function (TF). The rail corrugated profile is machined in the rail heads of the scale track following a periodic function with four harmonics. Experiments are performed with a scale bogie-like vehicle at different forward velocities in the range inspection velocities. Two simple analytical forms of the TF are studied: the kinematic TF, that assumes that the axle box follows the rail profile, and the TF of a 2-dof model of the vehicle-track system. For the vehicle response analysis, this work proposes to normalize the measured acceleration with the square of the forward velocity of the vehicle, that is assumed to be approximately constant. This normalized acceleration reduces the effect of the forward velocity on the TF. Experimental results show that the kinematic TF can be used to measure the track corrugation for moderate forward velocities providing reasonable but not accurate results.

Abstract ID: 186

Surrogate Model-Based MPC for Precise Maneuvering and Trajectory Tracking in Autonomous Bicycle Control

Miao, Xuyuan; Liu, Caishan
State Key Laboratory for Turbulence and Complex Systems, College of Engineering, Peking University, Beijing, China

Bicycle automation has gained significant attention for its potential to improve off-road transportation efficiency. To fully leverage the capabilities of autonomous bicycles, precise trajectory tracking and agile maneuverability in narrow spaces are crucial. However, the bicycle's handlebar steering simultaneously influences both its heading and lateral stability, posing substantial challenges for autonomous trajectory tracking and maneuvering. While methods such as PID, fuzzy control, and sliding-mode control have been explored, Model Predictive Control (MPC) stands out for its effectiveness in addressing the problem's sensitivity and dynamics-dependent behavior by explicitly incorporating the system's dynamic model. Nonetheless, its practical implementation is constrained by high computational demands and the need for rapid real-time responses. In this work, we propose a surrogate model-based MPC algorithm for bicycle trajectory tracking. The surrogate model, derived from the reduced dynamics of the Whipple bicycle model, allows the MPC to efficiently manage

complex dynamics and mitigate real-time latency through a modified multi-objective particle swarm optimization (PSO) algorithm. The proposed control strategy demonstrates strong performance in tracking straight paths from offset initial positions and navigating complex narrow paths.

Abstract ID: 187

Control of Nonholonomic Systems: Is Model Predictive Control a Universal Solution?

Ebel, Henrik[1]; Rosenfelder, Mario[2]; Eberhard, Peter[2]
[1]LUT University, Finland; [2]University of Stuttgart, Germany

Controlling nonholonomic systems is challenging, and difficulties increase with the degree of nonholonomy. Research on the control of nonholonomic systems has two key motivations, namely the desire to automate them and the fact that their challenging character makes them formidable test cases in the development of new nonlinear control methods. Today's drive for further-reaching automation as well as new possibilities for control, e.g., due to increased availability of computation power, have recently rekindled interest in controlling nonholonomic systems. At the same time, model predictive control (MPC) has become a very successful nonlinear control method in many fields of application. Curiously, it was not generally recognized until quite recently that typical MPC setups and methods to devise MPC design ingredients for asymptotic stabilization do not work for nonholonomic systems, and, thus, that systematic design methodologies to obtain asymptotically stabilizing MPC controllers for the class of nonholonomic systems were lacking. In this contribution, we recapitulate our recently introduced, novel design method to obtain functioning MPC controllers systematically for nonholonomic systems. Furthermore, we set the qualities of the approach in context with other control approaches, including reinforcement learning, and shed light on further-reaching topics like navigation around obstacles and data-based control.

Abstract ID: 188

Inverse Dynamic Analysis of a Cycloidal Speed Reducer

Cammarata, Alessandro[1]; Maddio, Pietro Davide[1]; Sinatra, Rosario[1]; Verotti, Matteo[2]; Serafino, Simone[2]; Fanghella, Pietro[2]
[1]University of Catania, Department of Civil Engineering and Architecture; [2]University of Genoa, Department of Mechanical, Energy, Management and Transport Engineering

The growing use of cycloid speed reducers stems from the need for high-speed reductions, combined with the demand for high torque, high efficiency, compact size, and low weight. The architecture of conventional reducers involves several components: for high transmission ratios, many large and heavy gears are needed to provide adequate torque capacity leading to lower efficiency. Furthermore, in conventional gear systems, the contact is either point or line contact, limited to a small number of teeth, resulting in high contact pressures that cause rapid wear. The cycloid drive uses a differential action principle that allows for high reductions without a multitude of components, and the contact areas are large since the number of teeth in engagement simultaneously is high: this enables high transmission ratios, large transmissible torques, high efficiency, compact dimensions, and reduced mass and inertia. Two different methodologies based on the penalty formulation have been used to investigate the inverse dynamics of a cycloid drive reducer. The first model uses rigid bodies, while the contacts were investigated using Hertz contact theory. The second formulation employs flexible bodies meshed with finite elements and the contact is based on the intersection of discretized profiles.

Abstract ID: 190

Multibody Modeling of Snapping Linkages

Huczala, Daniel
Unit of Geometry and Surveying, University of Innsbruck, Austria

In the talk, challenges and potential strategies for multibody modeling of snapping over-constrained mechanisms will be presented and illustrated with a practical example. Since kinematic synthesis methods are unable to account for the forces and deformations experienced by the mechanism, the only way to nowadays evaluate a mechanism is to build it and perform a practical test, which is very time and cost consuming. Flexible multibody modeling can address the presented problems that arise due to redundant constraints and help to optimize the kinematic design.

Abstract ID: 192

Comparative Analysis of Neural Network-Based and Data-Driven Methodologies for Long-Time Extrapolation in Multibody Dynamics

Choi, Hee-sun[1]; Jung, Min-Jae[2]; Han, Seok-Hee[2]; Yang, Hyeonseok[2]; Han, Seongji[3]; Kim, Jin-Gyun[2]
[1]Korea Atomic Energy Research Institute (KAERI), Korea, Republic of (South Korea); [2]Department of Mechanical Engineering(Integrated Engineering), Kyung Hee University; [3]Department of Mechatronics Engineering, Chungnam National University

This study investigates the long-time extrapolation capabilities of neural network-based and data-driven methodologies in multibody dynamics (MBD). Five representative methods were analyzed: Feedforward Neural Networks (FNN), Recurrent Neural Networks (RNN), Physics-Informed Neural Networks (PINN), Neural Ordinary Differential Equations (Neural ODE), and Sparse Identification of Nonlinear Dynamics (SINDy). Using pendulum systems as case studies, the research examines their performance over time intervals significantly beyond training data, focusing on accuracy, sensitivity to system dynamics, and data quality. All methods show strong interpolation performance, with PINN and SINDy excelling. However, in long-time extrapolation, LSTM, Neural ODE, and SINDy demonstrate superior performance in general, while FNN and PINN experience rapid accuracy declines. The study also highlights varying sensitivity to damping, chaotic dynamics, and noisy or non-uniform data, underscoring the importance of method selection based on specific system characteristics. The findings provide an advanced understanding of the strengths and limitations of these methodologies, particularly for long-term extrapolation in MBD, offering guidance for choosing the appropriate approach under different conditions.

Abstract ID: 194

Dynamic Modeling and Analysis of a Bionic Fish Driven by MFC

Xue, Youcheng; Li, Liang; Zhang, Dingguo; Guo, Xian; Guo, Yongbin
Nanjing University of Science and Technology, China, People's Republic of

As the combination of fish propulsion mechanism and robot technology, bionic robotic fish provides a new idea for the development of a new type of underwater vehicle, which has important research value and application prospect. Once put into use, bionic robotic fish will play an important role in complex and dangerous underwater environment operations, military reconnaissance, underwater

rescue, marine biological observation, environmental protection and so on. However, when MFC is used as the actuator of bionic robotic fishtail fin, there is a lack of accurate dynamic model to provide theoretical guidance and technical support. Therefore, this paper proposed a new dynamic modeling theory for underwater bionic fish driven by flexible intelligent materials. Based on the absolute nodal coordinate formulation(ANCF), the flexible deformation of fish tail driven by MFC was described. In addition, LBM and IBM methods were combined to calculate the changes of flow field and the impact on the deformation of fish tail in real time, and the theory was verified and optimized through experiments.

Abstract ID: 196

Dynamic Analysis of Membrane Wing Development Based on Absolute Node Coordinate Formulation

Wang, Bin; Liu, Caishan; Li, Jiaquan
Peking University, China, People's Republic of

The membrane wings are thin, compliant, and elastic, enabling them to adjust their curved shape to adapt to aerodynamic conditions passively. Therefore, they can enhance the aerodynamic performance of aircraft, execute special flight missions, and reduce structural weight. The deployable membrane wings studied in this paper further enable aircraft miniaturization, thus facilitating storage, transportation, and launch. The membrane wing deployment is a dynamic problem with variable volume, load, and boundary conditions. Analyzing the membrane wings' deployment mechanism and mechanical behavior during deployment is paramount. Therefore, an improved ANCF triangular shell element is used to discretize the deployable membrane wings whose stressed components remain taut and flat during the deployment process. The dynamic model incorporates time-varying rigid boundaries, wing surface area, and loads are established. By analyzing the influence of deployment modes and loads on the wing surface vibration, it is found that improving the deployment mode is an effective way to reduce the vibration of the membrane wing and enhance the aerodynamic stability.

Abstract ID: 197

An Updated Lagrangian Conservative Finite Element Method for Hyperelastic Materials

Gabaldon, Felipe; García, Juan Carlos; Arribas, Juan José
Universidad Politécnica de Madrid, Spain

In this article, a conservative formulation of energy and momentum is proposed for an incompressible hyperelastic model described with an updated Lagrangian scheme, using Q8/P1 mixed finite elements.

Abstract ID: 199

Port-Hamiltonian Formulation and Structure-Preserving Discretization of Geometrically Exact Beams

Kinon, Philipp L.[1]; Betsch, Peter[1]; Eugster, Simon R.[2]
[1]Karlsruhe Institute of Technology (KIT), Germany; [2]Eindhoven University of Technology (TU/e), The Netherlands

Port-Hamiltonian (PH) systems modelling — a framework that inherently guarantees energetic consistency and facilitates interconnection of physical systems — is gaining increasing popularity also in computational mechanics. Structural mechanical elements such as strings and beams, which often represent submodules in flexible multibody systems, are particularly well-suited for this approach. While the linearized Timoshenko beam that assumes small deformations and rotations is a common application example in PH works, we contribute with respect to two aspects that are only rarely addressed, but are eminently important in flexible multibody dynamics: 1) We propose a new PH formulation for the highly nonlinear dynamics of geometrically exact beams, also known as Simo-Reissner beams or special Cosserat rods, which are amenable to large deformations and rotations. 2) We analyze the structure-preserving spatial and temporal discretization using mixed finite elements and second order time stepping methods, ensuring the avoidance of locking and providing exact energy balance representation. Simulation results illustrate the performance of the developed approach. The gained insights highlight the potential of the PH framework for extending to more complex flexible multibody systems and advancing numerical treatments in computational mechanics.

Abstract ID: 200

Detection of Mechanical Clearances with Data-Driven Approaches

Nguyen, Vuong[1]; Rodríguez, Antonio J.[2]; Orzechowski, Grzegorz[1]; Mikkola, Aki[1]; Kim, Jin-Gyun[3]; González, Francisco[2]
[1]Department of Mechanical Engineering, LUT University; [2]CITENI, Universidade da Coruña, Spain; [3]Department of Mechanical Engineering (Integrated Engineering), Kyung Hee University Yongin-si

Joint clearances cause vibration and impacts in mechanical systems, decreasing machine efficiency and causing heat, noise, and additional wear. Clearances can eventually cause damage to components and lead to premature system failure. The monitoring and characterization of this defect are necessary tools in machine maintenance. Often, these tasks need to be performed using data from a reduced set of sensors, which is usually limited because industrial machinery does not include extensive sensor arrays. This work explores the prediction of the size of clearances through neural networks in a slider-crank linkage. All the experiments are conducted in a simulation environment. Through a multibody model of the mechanism, different datasets are generated, varying the clearance size and the initial velocity of the mechanism. Each dataset is divided into training, validation and testing with proportions of 70%, 15% and 15%, respectively. Using a Long Short-Term Memory network, the model is able to predict the clearance sizes, showing higher accurate at higher initial velocities.

Abstract ID: 202

A Novel Kalman Filter Approach for Clearances Estimation

Rodríguez, Antonio J.[1]; Sanjurjo, Emilio[1]; López-Lombardero, Mario[1,2]; Cabello, Mario[2]; González, Francisco[1]; Naya, Miguel Ángel[1]
[1]Laboratorio de Ingeniería Mecánica, CITENI, Universidade da Coruña, Campus Industrial, 15403 Ferrol, Spain; [2]IKERLAN, P◦ J. M. Arizmendiarrieta 2, 20500 Arrasate-Mondragón, Spain

Machinery maintenance is a topic of industrial interest: if a machine starts to malfunction, the whole process might be affected and lead to the interruption of the production. In many cases, malfunctions are related to the presence of wear between moving parts, also known as joint clearance. Being able to monitor the mechanism behaviour to detect the presence of clearance and observe its evolution is an interesting alternative. Instead of scheduling regular stops, maintenance actions could take place at the time at which they are really necessary, decreasing the downtime of the machinery and avoiding the replacement of components that are still functional. However, this strategy would require more sensors than the ones usually installed in industrial machinery, which are frequently very limited. As an alternative, this work proposes the use of an Unscented Kalman filter (UKF) to estimate the size of a radial clearance. Based on the frequency spectrum of the angular acceleration of the crank, the UKF is able to estimate the value of the radius of the clearance.

Abstract ID: 205

Reaction Uniqueness Problem in the Divide-and-Conquer Approach

Pękal, Marcin; Malczyk, Paweł; Wojtyra, Marek; Frączek, Janusz
Warsaw University of Technology, Poland

If a multibody system is overconstrained and modeled under the rigid-body assumption, problems with the non-uniqueness of some or all the reaction forces arise. This contribution presents a divide-and-conquer-based (DCA-based) method for the reaction uniqueness analysis. The approach requires building a global matrix of coefficients from the recursively calculated constituents. In the discussed method, this coefficient matrix (in the full or reduced form) is used to verify the reaction uniqueness. It may be done using one of the following numerical approaches: rank comparison, QR decomposition, SVD, or nullspace methods. All of them are considered. A spatial parallelogram mechanism is studied to illustrate the approach. The presented method may be used for a particular class of MBSs, broader than in the earlier proposed recursive version of the approach.

Abstract ID: 207

Active Vibration and Active Structural Acoustic Control of Simply Supported Plates

Hirschfeldt, Natasha; Furtmüller, Thomas; Adam, Christoph
Universität Innsbruck, Austria

Vibration control is a wide field of study that aims to modify a system's dynamic response as desired. This study uses different approaches of active vibration control to compare their effects on the sound pressure radiated by the vibrating structure, done by means of numerical analyses of simply

supported plates. These effects are compared with active structural acoustic control approaches where the feedback signal is directly related to the measured sound pressure instead of the vibration response. The study shows that although the vibration mitigation of the plate is achieved by active measures, it does not imply in a reduction of sound pressure. This means that it is possible to amplify the sound radiated by the plate when attenuating its vibration, an effect that is usually undesirable in practice. By simulating different active control approaches, it is also possible to compare sound pressure levels and gains required to achieve the desired control of the plate. The final goal is to evaluate which of the selected control approaches provides the best outcome in terms of both vibration and sound pressure reduction.

Abstract ID: 210

Flexible Multibody Dynamic Modeling of Mandibular Musculoskeletal System in Mandibular Fracture Patients and Its Utilization in Fixation Design

Wang, Xinyue[1]; Liu, Lu[2]; Guo, Jianqiao[1]; Wang, Xinyu[2]; Tian, Qiang[1]
[1]School of Aerospace Engineering Beijing Institute of Technology; [2]Stomatological Collage of Jiamusi University

Mandibular fractures account for 35.5% to 44.2% of all maxillofacial fractures. It can cause bone displacement and occlusion disorders, seriously affecting the patient's life quality. Rigid internal fixation (RIF) is a well-known treatment method for mandibular fracture, and the miniature titanium plate is a small implant for RIF treatment with high biocompatibility. However, how to design the titanium plate to maintain the stability of bone segments with the smallest volume remains to be addressed. The finite element method (FEM) modeling has been widely used in biomechanical studies of mandibular fractures. However, the FEM models introduced a large number of DOFs and often focused on quasi-static conditions like chewing. Multibody dynamics modeling can estimate the muscle recruitment patterns and their impact on jaw movement functions at a relatively low computational cost. This study proposed a flexible multibody dynamic modeling for patients with mandibular fractures. Based on the geometrically exact beam formulation (GEBF), the proposed model was further utilized in customized design methods for titanium plate implants.

Abstract ID: 211

Towards Real-Time Capable and Physics-Based Terramechanics for Simulating Robot-Terrain Interaction

Unjhawala, Huzaifa Mustafa[1]; Bakke, Luning[1]; Serban, Radu[1]; Yang, Lijing[1]; Hu, Wei[2]; Negrut, Dan[1]
[1]University of Wisconsin Madison, United States of America; [2]Shanghai Jiao Tong University, China

For the effective use of simulation in the engineering design of vehicles & robots operating in off-road, unstructured, and harsh environments, simulators must be both accurate and fast. Accuracy ensures that design decisions made in simulation translate reliably to real-world applications. Speed is critical to facilitate rapid design iterations and fast time-to-market cycles. Existing simulation solutions for terramechanics often compromise between these requirements. For example, Chrono's Soil Contact Model (SCM), based on Bekker-Wong/Janosi-Hanamoto theory, achieves real-time performance but relies on semi-empirical methods, necessitating extensive experimental calibration. Additionally, it lacks support for a broad spectrum of robot-terrain interaction scenarios, such as digging, grading,

and other complex soil manipulation tasks. Conversely, Chrono's SPH-based Continuous Representation Model (CRM) is fully physics-based and extensively validated across diverse robot-terrain interactions. However, its simulation speed is approximately 500 times slower than real-time, making it impractical for many use cases. This work presents recent CUDA optimizations to Chrono CRM's existing GPU implementation, achieving close to real-time simulation speeds without sacrificing accuracy. We demonstrate runtime improvements of up to 10X across six diverse test cases anchored in real-life applications.

Abstract ID: 212

Dynamic Modeling of an Origami-Inspired Microgripper with Curved Creases

Yuan, Tingting[1]; Liu, Jinyang[2]; Zhang, Wei[1]

[1]Guangxi University, Nanning, People's Republic of China; [2]Shanghai Jiao Tong University, Shanghai, People's Republic of China

Biomedical applications inspired by origami have accrued aspired advances, due to its excellent capability in compact deployment and shape-shifting, as well as its extraordinary mechanical properties. With the development of robotic-assisted minimally invasive surgical techniques, the requirements for surgical grippers have gradually improved. However, existing surgical forceps generally suffer from high friction, low mechanical efficiency, and complicated assembly process of components. Therefore, a novel curved origami-inspired surgical microgripper is designed and investigated in this paper. Since the curved origami structure is characterized by its miniature size and lightweight, multiple-point contact inevitably occurs between the large deformatable gripper and the object during the manipulation, thereby presenting a greater challenge for dynamic research. A dynamic model of the origami-inspired microgripper that integrates geometric nonlinearities, frictional contact and crease bending effects is developed. The dynamic analysis of the origami-inspired microgripper is carried out, focusing on the influences of loads, friction, and response speed to the gripping process. Furthermore, the relationship between geometric parameters (e.g., crease curvature), material parameters (e.g., crease stiffness) and the stiffness of curved origami is deeply investigated.

Abstract ID: 213

Subject-Specific Modeling for the Scoliosis Spine Based on Geometrically Exact Beam Theory

Xiao, Zuming[1]; Guo, Jianqiao[1]; Guo, Wei[2]; Liu, Xiaomin[3]; Tian, Qiang[1]

[1]School of Aerospace Engineering, Beijing Institute of Technology, China, People's Republic of; [2]PLA TCM manipulative orthopedic therapy department, Air Force Medical Center, China, People's Republic of; [3]School of Information Science and Technology, Beijing University of TechnologyBeijing University of Technology, China, People's Republic of

Adolescent idiopathic scoliosis (AIS) is a spinal deformity commonly seen in teenage girls. It is crucial to estimate the dynamic response of the AIS spine. However, most existing musculoskeletal models did not consider the nonlinear rotation and deformation mechanism of intervertebral discs, and the three-dimensional spinal curvatures of the AIS patients were difficult to personalize in biodynamic models. In this study, a subject-specific musculoskeletal model was established according to ten geometrical parameters measured from X-ray imaging. The geometrically exact beam was further utilized to replace the rigid-body description of each vertebra. By this means, the AIS spine can be regarded as a Timoshenko beam with large deformation, and its nodal coordinates were identical to the vertebral postures. The proposed method has been utilized in vibration mode and sit-to-head transmissibility (STHT) analysis. The proposed flexible multibody model successfully revealed the biodynamic behavior of the AIS spine: the first-order resonant frequency was higher than that of the generic model, and the STHT magnitude of the AIS spine was decreased by its out-of-plane vibrations.

Abstract ID: 214

A Runtime-Optimized Simulation Tool for Determining the Interaction of Catenary and Pantographs

Minor, Lion[1]; Cleven, Raphael[1]; Doelling, Andre[2]; Corves, Burkhard[1]
[1]RWTH Aachen University, Germany; [2]Siemens Mobility GmbH

Electrified railway tracks provide the most efficient energy supply for rail vehicles, with simulations of catenary-pantograph interaction playing a key role in the approval process. A critical requirement is to minimize simulation time while ensuring precise results. This work aims to develop a fast and accurate simulation model, representing the pantograph as a three-mass oscillator and modeling the catenary with wires, droppers, and supports. The wires are modeled with the Ritz-approach. In this method, various shape functions are multiplied by weighting factors to derive the wire's motion. The mass and stiffness matrices are obtained from energy calculations using the wire's motion. Damping is considered with Rayleigh-damping. The individual matrices for the wires, the pantograph model and the interlinking effects are combined into an overall equation of motion. Results are computed using the solvers ode45, central differences and Hilber-Hughes-Taylor. The accuracy of these results is validated against a high-speed AC reference catenary from EN 50318 while also comparing the simulation times of different solvers.

Abstract ID: 216

Kinematic Analysis of a Parallel-Actuated Cylindrical Joint

Molla-Santamaria, Paula; Peidro, Adrian; Fabregat-Jaen, Marc; Paya, Luis; Reinoso, Oscar
Miguel Hernandez University, Spain

This work presents the kinematic analysis of a parallel mechanism that is to serve as an actuated cylindrical joint for a new tree-climbing quadruped robot. Existing actuated cylindrical joints in the literature are difficult to implement in the proposed quadruped robot due to the arrangement of bodies and joints in this robot, so a new actuation strategy is studied in which the cylindrical joint is actuated through two Universal-Prismatic-Spherical (UPS) limbs connected in parallel between the two bodies articulated by the cylindrical joint, where the prismatic joints of these limbs are actuated. It is shown that the forward kinematic problem of the resulting 2UPS-C parallel mechanism, which provides the computation of the translational and rotational displacements of the cylindrical joint from the extension of the prismatic joints, boils down to solving a 4th degree polynomial, which admits analytical solution. Moreover, singularity analysis shows that the 2UPS-C mechanism is cuspidal, admitting transitions between different forward kinematic solutions without meeting singularities.

Abstract ID: 217

An Efficient Reconstruction Scheme of Signed Distance Fields for Contact Detection Between Flexible Bodies

Tang, Tiantian; Luo, Kai; Tian, Qiang; Hu, Haiyan
Beijing Institute of Technology, Beijing, China

In this paper, an efficient reconstruction scheme of signed distance fields (SDF) for contact detection between flexible bodies is proposed. When two bodies come into contact, the SDF method implicitly represents the surface of the master body using discrete signed distance values on the vertices of spatial voxels. Thus, the contact process can be seen as a slave body immersed within an Eulerian solid. Unlike previous SDF-based methods, the proposed approach offers a rapid SDF reconstruction of the current configuration of the master surface using the gappy POD method. The accuracy of the reconstructed SDF is validated through tests involving a 3D plate undergoing large deformations. Building on this, a node-to-surface contact algorithm, integrated with a penalty function method, is developed for dynamic contact problems between flexible bodies. The performance of the proposed algorithm is demonstrated through dynamic simulations of a sphere impacting a plate, with results compared to those derived from the axis-aligned bounding box (AABB) method.

Abstract ID: 218

Evaluating Physical, Hybrid, and Data-Driven Models for Rubber-Metal Bushings: Balancing Accuracy, Complexity, and Efficiency

Wohlleben, Meike[1]; Schütte, Jan[1]; Berkemeier, Manuel[2]; Sextro, Walter[1]; Peitz, Sebastian[2]
[1]Paderborn University, Chair of Dynamics and Mechatronics, Germany; [2]TU Dortmund University, Department of Computer Science, Germany

Rubber-metal bushings (RMB) are essential components in multibody systems, such as vehicles and industrial machinery, due to their ability to enable relative motion, dampen vibrations, and transmit forces. Their nonlinear behavior poses significant challenges for accurate modeling. Traditional physical models, like Kelvin-Voigt and generalized Maxwell models, are commonly used to describe RMB behavior but have limitations in balancing simplicity, accuracy, and computational effort. The increasing availability of experimental data opens new possibilities for hybrid and data-driven approaches. This study compares physical models with hybrid and data-driven methods to evaluate performance in terms of modeling effort, predictive accuracy, and computational cost. Hybrid approaches integrate machine learning techniques alongside traditional models. Additionally, purely data-driven methods, including Dynamic Mode Decomposition with control (DMDc) and feed-forward neural networks, are explored. The results show that hybridizing more complex models, such as the generalized Maxwell model, increases computational cost without considerably increasing accuracy. In contrast, hybrid methods significantly improve accuracy for simpler models like Kelvin-Voigt with a modest rise in computational time. These findings suggest that hybrid methods can simplify RMB modeling while balancing accuracy and efficiency, but their benefits depend on the underlying model complexity. This work provides insights for advancing multibody system simulations.

Abstract ID: 219

Modeling and Experiments on Stable Stepladder Walking

Polach, Pavel[1]; Papáček, Štěpán[2]; Anderle, Milan[2,3]
[1]Research and Testing Institute Plzen, Czech Republic; [2]Institute of Information Theory and Automation, The Czech Academy of Sciences, Czech Republic; [3]Faculty of Mechanical Engineering, Czech Technical University in Prague, Czech Republic

Modeling and control of underactuated mechanical systems, such as bipedal robots, remains a challenging task despite decades of intensive research. This study examines a less common but conceptually similar mechanical system: a stepladder with a decorator/operator. The system features nonlinear, high-dimensional, and hybrid dynamics. The primary objective is to identify the stable cyclic walking behavior of the stepladder induced by specific actuation patterns of the decorator. To achieve this, we first establish a detailed 3D model of the system with time-dependent actuation parameters derived from a video sequence. Subsequently, we develop multiple variants of 2D reduced-order models (ROMs) to capture the system's essential dynamics. The parameters of these ROMs are identified by solving an inverse problem using data extracted through image-processing software. Finally, a suitable ROM is selected to approximate the system dynamics and synthesize a stable cyclic walking motion in some sense optimal.

Abstract ID: 220

Numerical Comparison of the Continuous and the Discrete Adjoint Method for Sensitivity Analysis of Multibody Systems Using Various Integration Schemes

Keller, Mirko; Schmidt, Timo Hendrik; Held, Alexander; Seifried, Robert
Hamburg University of Technology, Germany

Gradient-based optimization is an established tool to improve the performance of dynamical systems. This requires sensitivity information depending on the optimization problem. The adjoint variable method is often the most efficient approach to perform the sensitivity analysis of multibody systems. In this work, the continuous and the discrete adjoint method are applied to the sensitivity analysis of rigid multibody systems using various integration schemes. The multibody systems are formulated as differential algebraic equations and then transformed into ordinary differential equations. The numerical behavior of both adjoint methods is investigated and compared to each other. In particular, numerical problems that arise when using the continuous adjoint method are addressed.

Abstract ID: 221

Real-Time Simulation of Flexible Bodies with Ray-Traced Contact in the Unity Game Engine

Zobel, Oliver Maximilian[1]; Zwölfer, Andreas[1]; Weber, Tobias[2]; Rixen, Daniel[1]
[1]Chair of Applied Mechanics, TUM School of Engineering and Design, Germany; [2]Boeing Research & Technology - Europe

Computer simulations in structural mechanics, such as Finite Element Method (FEM) models, are traditionally performed offline, limiting real-time interaction during simulations. This paper explores

using a game engine, specifically Unity, to enable interactive, real-time simulations with changing parameters or boundary conditions. While game engines excel in visualization and user input, they lack physically accurate simulations. To address this, the implementation utilizes the Floating Frame of Reference Formulation (FFRF) for flexible bodies, incorporating linear FEM models for accurate physics. A commercial FEM program, Abaqus, is used to prepare the model and export necessary data. Users can interactively modify boundary conditions, manipulate flexible bodies, and simulate contact scenarios. Contact simulation is enabled through ray-tracing-based contact search and a penalized contact formulation. The implementation is validated against Abaqus and benchmarked for computational performance on consumer-grade hardware, demonstrating its feasibility for interactive structural mechanics simulations.

Abstract ID: 223

Control of Underactuated Systems Based on Machine Learning Model: Case Studies

Zelei, Ambrus
Szechenyi Istvan University, Hungary

The rapid pace of industrial development has significantly increased the demand for virtual testing of machines and control algorithms. Besides traditional simulations, machine learning are getting widespread: certain subsystems or even the entire simulation model is replaced by neural network models. This work studies the possibilities of the application of neural network models to substitute the dynamic equations of multibody systems. The neural network model is provided by the Scikit-learn Python package. The approach is demonstrated in three levels: the dynamics of minimum-coordinate models, the dynamics of constrained models and the control of underactuated multibody systems. The neural network model is utilized to represent the inverse dynamics model in the under-actuated control problems. The core idea is that the training data for the inverse dynamics model is based on forward dynamic simulations. The pilot study demonstrates that a physical pendulum can be approximated by a small-scale neural network, with training time about a second on a personal computer.

Abstract ID: 225

Prediction of the Wear Behavior of a Conveyor Belt with Flexible Rollers

Vogl, Yannick Marius[1]; Schulz, Carsten[1]; Schaeffer, Thomas[1]; Geiger, Benjamin[2]
[1]OTH Regensburg, Germany; [2]BHS Corrugated Maschinen- und Anlagenbau GmbH, Germany

This paper introduces a method to predict wear behavior in conveyor belt systems using a lumped mass modeling approach. While previous research has focused primarily on lateral belt walking, this study shifts attention to belt deformation and its associated wear. Both significantly affect system efficiency and component lifespan. The authors propose using local frictional power as a wear indicator, leveraging its direct relation to frictional work in established wear models. To validate the method, the study simulates a conveyor belt with three flexible rollers and a deformable belt modeled through rigid

spheres connected by spring-damper elements. The authors quantify and visualize frictional power density across the belt width, distinguishing between running and transverse directions. The results demonstrate that the frictional power distribution depends heavily on discretization quality, particularly due to the polygon effect inherent in the lumped mass approach. A convergence analysis reveals a minimum discretization of nine sphere rows with 557 spheres per row to achieve reliable qualitative insights. This method enables researchers to evaluate wear distribution in flexible conveyor systems and adapt the approach for broader applications in multibody dynamics. Future work should refine discretization techniques and friction models to enhance quantitative accuracy.

Abstract ID: 226

Wheel Wear Dynamics in Sharp Curves: Insights From T-Gamma Indicator Study on Heavy-Haul Railways

Pacheco, Philipe Augusto de Paula[1,2]; Lopes, Mateus Valente[2]; Santos, Auteliano Antunes[2]
[1]Federal Institute of the Southeast of Minas Gerais, Brazil; [2]Universidade Estadual de Campinas

The dynamic interaction between railway wheels and rails is critical for ensuring maintenance and safety in railway operations. Accurate assessment of wheel wear is essential, particularly in sharp curves where wear is more pronounced. This study focuses on the use of the T-gamma ($T\gamma$) indicator to quantify wheel wear in sharp curves. This research evaluates a meter gauge heavy haul vehicle from a Brazilian railway. Comprehensive multibody simulations were conducted on various sharp curves to investigate the relationship between $T\gamma$, the maximum penetration under varying speeds, and the non-compensated lateral accelerations (Anc). The findings indicate that the total $T\gamma$, which includes both the $T\gamma$ values from the tread and the flange, is more effective for analyzing wear depth compared to examining the $T\gamma$ values individually for the tread and flange. The results also show the high influence of Anc on flange wear depth. There is also a strong relationship between tread wear depth and Anc, except for the sharpest and widest curves, which have low Anc influence. By focusing on sharp curves, this study aims to deepen the understanding of wheel-rail wear dynamics in such challenging conditions and provide valuable insights for improving maintenance strategies and enhancing railway safety.

Abstract ID: 227

Floquet Stability Analysis of Simplified Railroad Track Models

Brazales, Álvaro[1]; Chamorro, Rosario[2]; Fernández, Javier[1]
[1]University of Jaén, Spain; [2]University of Seville, Spain

This work investigates the stability of simplified railroad track models employed in multibody simulations of railway vehicles. These computational models represent the railway track using lumped masses and rigid bodies interconnected by spring-dashpot elements, offering an efficient approximation of the flexibility of discretely supported tracks. Despite limitations such as longitudinal decoupling and the number of degrees of freedom required to model the dynamics of a railroad track over a wide frequency range, the simplified railroad track models mitigate some drawbacks of detailed railway track models, including finite-length issues and high computational costs. Periodic variations in railway track properties introduce time-varying stiffness terms in the equations of motion of the simplified railroad track models, potentially leading to instabilities in the absence of external forces.

A numerical procedure based on Floquet theory is proposed to construct stability diagrams for these simplified models, offering valuable insights into their parametric instability regions. The methodology is demonstrated on a 1-DOF model governed by a periodically damped Mathieu equation and can be extended to more complex moving railroad track models with higher degrees of freedom or alternative formulations for receptance variation.

Abstract ID: 228

Chrono::PowerElectronics an Open-Source Simulation Package for Complex Electro-Mechanical Problems: A Validation Study

Reato, Federico Maria[1]; Santelia, Matteo[2]; Witt, Bret[3]; Ruiz, Alexis[3]; Ricci, Claudio[1]; Morlacchi, Filippo[1]; Zama, Maurizio[1]; Negrut, Dan[3]
[1]R&D Mechatronics, Iseo Ultimate Access Technologies, Italy; [2]Department of Mechanical Engineering, Politecnico di Milano, Italy; [3]Department of Mechanical Engineering, University of Wisconsin-Madison, USA

In understanding the dynamics of electro-mechanical systems through simulation, a classic investigation approach is to address each physical macro-domain (mechanical, electrical or magnetic) separately, using specialized software tailored to address the domain-specific physics. This approach might require long simulation run times, when high accuracy is required. In this full contribution, we report on Chrono::PowerElectronics (Chrono::PE), a specialized module within the open-source multi-physics simulation framework, Chrono. The proposed library is designed for modeling and simulating robotics, mechatronics, and highly-coupled electro-mechanical systems. It combines the multi-physics dynamics open-source engine, Project Chrono (PC), with the versatile open-source circuit simulator NGSpice (NGS) to solve complex dynamic interactions between the mechanical and electronics domains. To validate Chrono::PE, we report on a detailed comparison conducted using Matlab-Simscape as a benchmark. The test considered analyzes an analog electronic circuit that controls a DC motor via PWM signals. The results obtained with Chrono::PE are compared with numerical data obtained from a Simscape model replica. The drive control of the DC motor system effectively highlights the strong interdependence between mechanical and electrical parameters, e.g., inertia, friction, current, and back e.m.f., while maintaining a simplified and straightforward benchamark scenario.

Abstract ID: 229

Impact of Shear and Extensional Stiffness on Equilibria of Elastic Cosserat Rods - An Update

Linn, Joachim; Roller, Michael; Schneider-Jung, Fabio
Fraunhofer ITWM, Germany

In our recent contribution to the previous conference we presented first results of theoretical and numerical investigations of the influence of the effective extensional and shear stiffness parameters [EA] and [GA] on the deformed shapes and strain measures of an elastic Cosserat rod model in equilibrium. In our forthcoming contribution we extend our investigations to spatial deformation cases. Besides the analysis of extensional and shear strains, we also compare the extensional and transverse shear forces. For Cosserat rods the latter can be computed via linear constitutive stress-strain type equations, while they have to be determined in a completely different manner as Lagrange multipliers for Kirchhoff rods.

Abstract ID: 231

A Study Into the Robustness of Visual-Language Models for Zero Shot Semantic Robot Navigation

Ashokkumar, Sriram; Zhang, Harry; Unjhawala, Huzaifa; Negrut, Dan
University of Wisconsin Madison, United States of America

Recent developments in Vision-Language Models (VLMs) have started to impact robotics applications, e.g., in mapping and localization tasks. This study evaluates a recent contribution that produces Vision-Language Frontier Maps (VLFM). The authors introduce a novel approach to integrating a VLM into object-goal robotics navigation problems. By leveraging VLM's reasoning capabilities, VLFM demonstrates efficient planning strategies for robots to reach various goals. While the VLFM method demonstrates promising results under its original experimental setup, this study investigates its robustness and performance across broader environments and sensor configurations, such as poor lighting, low-resolution cameras, and other challenging conditions. We seek to understand the method's failure modes and explore its real-world applicability, as the adoption of robots in indoor home environments depends on safe and reliable autonomy solutions. To address these concerns, we evaluate the VLFM framework using a robotics simulator with high-fidelity camera simulation support. Additionally, we assess the framework's performance in challenging conditions, including poorly lit or extremely bright rooms, to gain a comprehensive understanding of its limitations and real-world viability.

Abstract ID: 232

Multi-Body Pseudo-Rigid Modeling of Helical Gears

D'Angelo, Luca; Autiero, Matteo; Cirelli, Marco; Paoli, Giovanni; Valentini, Pier Paolo
University of Rome Tor Vergata, Italy

Power transmission systems rely on helical gears, but their dynamic behavior and intricate load distribution necessitate precise modeling for reliable performance. In order to overcome these challenges, this work develops and evaluates two pseudo-rigid multibody models with three-dimensional contact to faithfully capture the helical gears' flexibility and dynamic behavior. The first approach models the gear-tooth interaction featuring an inclined revolute joint that incorporates torsional stiffness, while the second uses a spherical joint with a stiffness matrix, considering a more complex flexibility and kinematics. Both models were compared with high-fidelity finite element simulations carried out under quasi-static conditions. The spherical joint model showed higher precision in describing load distribution and deformation, thus nearly matching the quasi-static transmission error results predicted by FEM. Conversely, the accuracy of the inclined revolute joint model was limited by its excessive rigidity. As a result, the spherical joint model shows great promise for precise and effective helical gear dynamic analysis. This approach will be extended to fully dynamic settings and, due to the 3D contact formulation, may incorporate wear, mounting errors and geometry modifications.

Abstract ID: 233

Modeling and Optimal Control of a Vertical Take-Off and Landing UAV

Figat, Marcin; Kania, Katarzyna; Kwiek, Agnieszka; Tarnowski, Andrzej; Pikuliński, Maciej; Malczyk, Paweł
Faculty of Power and Aeronautical Engineering, Warsaw University of Technology, Poland

Two types of Unmanned Aerial Vehicle (UAV) can be distinguished, the first group is multi-rotor, which can vertically take-off and land, however, the range and maximum speed is limited due to the lack of a wing and forward engine. Fixed-wing designs belong to the second group, a higher speed and longer range are the advantages but the landing and take-off procedures require more space. To ensure good performance and capability of vertical take-off and landing, those two concepts can be combined. However, the control of such a design is inherently more complex and requires special care of aerodynamic behavior and the transition dynamics between hovering and forward flight. Unlike traditional UAVs that operate predominantly in a single mode, hybrid designs must integrate two distinct flight regimes. This integration demands advanced control capable of managing aerodynamic changes and ensuring stability during transitions. To meet these challenges and inspired by research papers, it is planned to utilize the adjoint method within the model predictive control (MPC) framework, specifically designed to control the vehicle's attitude and thrust.

Abstract ID: 234

Satellite-Rocket Separation Mechanism Dynamics Analysis and Experimental Verification

Li, Jiaquan; Guo, Xiaoyue; Liu, Caishan
College of Engineering, Peking University, Beijing, China

Due to payload fairing size constraints, satellites often adopt a highly inclined and asymmetrical configuration relative to the rocket. This causes the center of mass of the rocket-satellite system to misalign with the force from the separation mechanism, resulting in significant angular velocity disturbances during separation. The separation process is complex, involving multi-point contact and varying constraints, with contact forces and preload parameters greatly influencing the disturbance. However, Hertz contact models, commonly used for multi-body problems, introduce errors due to uncertain non-physical parameters.To address this, we propose a model reduction-based dynamics approach for satellite-rocket separation. By analyzing the relative motion of contact surfaces, the separation system is modeled as a multi-stage linkage mechanism, allowing explicit kinematic relationships among components. This reduced-order model avoids implicit constraints and enables optimization of preload parameters to minimize post-separation angular velocity disturbances. The optimized parameters were successfully applied to the Jielong-3 launch vehicle, with in-orbit separation results closely matching theoretical predictions.

Abstract ID: 235

Practical Computation of Initial Sensitivities in Dynamics of Flexible Multibody Systems

García Orden, Juan Carlos; Arribas Montejo, Juan José; Felipe, Gabaldón Castillo; Daniel, Dopico Dopico
ETSI Caminos. Universidad Politécnica de Madrid, Spain

Sensitivities appear in practice in different situations while analyzing the dynamics of multibody systems. They are computed evaluating the corresponding derivatives respect the parameters around the reference movement. These derivatives are functions of time and are the solutions of a system of linear differential equations (with variable coefficients) named Tangent Linear Model (TLM). This TLM, that can be solved in advance or simultaneously with it, must be complemented with a set of initial conditions that have to satisfy the constraints. This contribution presents details about the calculation of these initial sensitivities, both for positions and velocities, for flexible bodies; specifically for those represented with beams and solid 2D and 3D finite elements. These calculations are tipically ommited in the literature, but are essential. The formulation is presented and some test are performed illustrating the performance of the proposed methodology.

Abstract ID: 239

PINNs: The Domain Decomposition Approach for Solving Inflatable Membrane Contact Problem

Shen, Xinyi; Sang, Xiaoyu; Liu, Caishan
Peking University, China, People's Republic of

The inflatable membrane contact problem is essential because it replicates many real-life scenarios: airbag cushioning, balloon angioplasty, etc. However, nonlinear geometric deformation of the membrane and variable boundaries of the contact region make the problem difficult to solve. This study aims to utilize Physical Informed Neural Networks (PINNs) to construct the membrane deformation in different subdomains and obtain the contact region boundaries by optimization. The compression of a linear elastic cylindrical membrane between the rigid sphere and plate is analyzed. The frictionless contact condition and adiabatic thermodynamic condition are assumed. The sigmoid function is used to construct window functions, which constrain PINNs to the corresponding subdomain. Based on the universal approximation theorem of neural networks and the framework of automatic differentiation, this study transforms solving the differential equations into an optimization problem. The loss function consists of boundary residuals and differential equation residuals. The results show that PINNs with the domain decomposition approach have the great potential to solve the complex contact problem.

Abstract ID: 240

Modal Reduction for Geometrically Nonlinear Slender Structures

Otsuka, Keisuke[1]; Sugiyama, Hiroyuki[2]
[1]Tohoku University, Japan; [2]The University of Iowa, USA

Slender structures are expected to be used for next-generaation aircraft, wind turbine, robot arm etc. However, such slender structure cannot avoid geometrically nonlinear deformation. Absolute

nodal coordinate formulation (ANCF) has been introduced into the dynamic analysis of the slender structure. The straightforward geometry description of ANCF is effecitve for aerodynamic mesh generation around aircraft/wind turbine and contact surface modeling of robot arm. Although the modal reduction approach has been developed for ANCF, it requires successive linearization in time-domain dynamic analysis. In this paper, we present a strain-based modal reduction method for ANCF that does not require successive linearization. In a simulation example, the two order of the model size reduction was achieved while retaining analysis accuracy.

Abstract ID: 241

Design and Performance Analysis of the Traction System of an Inboard Bogie

Baek, Seung Koo; Jeon, Chang Sung; Shin, Yu Jeong
Korea Railroad Research Institute, Korea, Republic of (South Korea)

This study deals with the design framework of a traction motor system for application to inboard bogies for high-speed rail. Recently, there are increasing cases of applying the inboard bogie system to newly manufactured trains in Europe[1][2], but there are no cases of development and application in Korea. Compare to outboard bogies, the inboard bogie is a technology that reduces vehicle weight and running resistance by 30%. However, despite these advantages, due to the disadvantage that the inner space of the bogie is reduced because the axle is located inside the wheel of the bogie, an optimization design and interface between the traction motor and the driving gear are required. In this study, two types of traction systems are proposed. One is a combined structure of a traction motor and driving gear which are mainly used traction systems for the high-speed trains(HST), the other is gearless traction system using a direct driving motor(DDM). The traction motor is designed as an interior permanent magnet synchronous motor(IPMSM) type. Electromagnetic and thermal analysis by finite element analysis(FEA) software[3] shows the feasibility of two types of the traction system designs.

Abstract ID: 244

Contact-Rich Assembly Operations Based on Visuotactile Sensing

Guo, Xiaoyue[1]; Ma, Daolin[2]; Liu, Caishan[1]; Wang, Bin[1]
[1]Peking University, China, People's Republic of; [2]School of Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai, China

Efficiently simulating interactions during contact and performing high-precision assembly operations remain core challenges in robotics. However, there is currently a lack of research on multimodal information fusion and effective control strategies. In this work, we leverage a self-developed high-precision visuotactile robotic simulation platform to explore the effective integration of visuotactile information. We propose an innovative learning strategy that integrates the expressive capabilities of heterogeneous point cloud representation with a two-stage distillation framework. By training intelligent algorithms with large-scale, high-precision visuotactile simulation data, we have enhanced contact information completeness and spatial consistency, further optimizing operational strategies in uncertain environments. Our approach is evaluated on contact-rich tasks, demonstrating robust reinforcement learning strategies and achieving high-precision simulation results.

Abstract ID: 246

Flexible Multibody-Fluid Coupling Dynamics Based on IB-LBM and ANCF

Qin, Yifan; Tian, Qiang; Shan, Minghe; Hu, Haiyan
Beijing Institute of Technology, China, People's Republic of

The study on coupling dynamics of flexible multibody-fluid interactions is important for the design of aircraft, flying biomimetic systems and underwater soft robots. Despite advancements in fluid-structure interaction methodologies, existing approaches often face challenges in handling the complexities of flexible multibody systems, such as large deformations and rotations, which create dynamic fluid boundaries. To overcome these challenges, a novel computational methodology is proposed. The fluid dynamics are modeled using the Lattice Boltzmann Method, and the flexible multibody systems are represented through the Absolute Nodal Coordinate Formulation. The two systems are coupled using the Immersed Boundary Method to enforce boundary conditions. A structural predictor is introduced to ensure synchronization of the time integration. This methodology ensures accurate energy transfer at the fluid-structure interface, thereby maintaining numerical stability. The proposed methodology is validated through three benchmark cases. The flight dynamics of a flexible biomimetic butterfly are also simulated to demonstrate that the proposed methodology can effectively address complex flexible multibody-fluid interactions.

Abstract ID: 247

Real-Time Analysis with the Generalized-Alpha Method for Steering Torque Simulator

Shiiba, Taichi; Yazawa, Takuma
Meiji University, Japan

The steering torque of an automotive is very important because it determines the driving and steering response of a vehicle. Steering torque characteristics are affected by the mechanical properties of the steering system, such as torsional stiffness, steering wheel inertia, and mechanical friction caused by the rack's sliding motion relative to bearings and seals. When evaluating vehicle handling and stability using a steering torque simulator, it is necessary to account for these effects in the steering torque calculation. The purpose of this study is to realize a stable and accurate real-time steering simulation with a larger time step while considering the friction phenomenon. For this purpose, the generalized alpha method was used, which can provide numerical damping for high-frequency phenomena while maintaining accuracy for low-frequency phenomena.

Abstract ID: 248

Dynamic Analysis for Lateral-Torsional Coupled Vibration in a Bolted Joint Dual-Rotor System Considering Interface Multi-Scale Contact State

Zhu, Zhimin; Zhang, Dingguo; Guo, Xian; Li, Liang
Nanjing University of Science and Technology, China, People's Republic of

Bolted joint structures are widely utilized in the aeroengine compressor rotor systems for convenience in assembly and maintenance. That will introduce numerous mating interfaces in the system and induce complex contact problems, causing a dramatic change in the local stiffness and damping and affecting the lateral-torsional coupled vibration performance of the system. Thus, the present work established a lateral-torsional dynamic model of the bolted joint dual-rotor system considering the interface multi-scale contact state by adopting the Iwan model and lumped methods. The relevancy mechanism between lateral-torsional coupled vibration and the evolution of interface multi-scale contact state, as well as its effect on the rotor dynamic response, is evaluated numerically and experimentally. The results indicate that the continuous frequency spectra and high-order harmonic frequency in the lateral and torsional frequency spectrum of the rotor system are attributed to the change of interface contact state, and the torsional vibration of the rotor system is more sensitive to this change. The research results can provide valuable insights into the dynamic properties prediction and health monitoring of a bolted joint dual-rotor system.

Abstract ID: 252

Investigating Subsystem Synthesis Method for Real-Time Multibody Dynamics

Jo, Seongmin[1]; Han, Seongji[2]; Kim, Jin-Gyun[1]; Kim, Sung-Soo[2]
[1]Kyung Hee University, Korea, Republic of (South Korea); [2]Chungnam National University, Korea, Republic of (South Korea)

Recently, the subsystem synthesis method is well known for effective simulation for complex real-world multibody dynam- ics (MBD) models such as vehicle dynamics, underwater robotics, etc. In the subsystem synthesis, each subsystem attached to a main body is represented by an effective inertia mass and force vector, which can be incorporated into the main body (referred to as the base body). Thus, different formulations can be applied to each subsystem. This can reduce the variables in the equations of motion of the multibody system and achieve efficiency to meet real-time simulation. In this study, three common coordinate systems, which are relative Cartesian coordinates, relative joint coordinates, and Cartesian coordinates were implemented within the subsystem synthesis formulation to evaluate the computational efficiency and effectiveness in subsystem assembly.

Abstract ID: 253

Analysis of a Ball Vibration Absorber with Focus on Evaluation of the Rolling Condition Boundary

Bulín, Radek; Dyk, Štěpán; Rendl, Jan; Hajžman, Michal
NTIS - New Technologies for the Information Society, Faculty of Applied Sciences,University of West Bohemia, Czech Republic

In general, tuned mass dampers (TMDs) are mechanical systems whose purpose is to reduce vibrations of a dynamically loaded structure. Their mechanical properties are commonly tuned, so the primary structure vibration amplitude is attenuated to an acceptable level at the required frequency range. In this paper, the ball vibration absorber (BVA), which is a nonlinear rolling type of TMD, is analysed, and the aspect of rolling condition fulfilment within the nonlinear analysis of the BVA is addressed. It is shown that the rolling condition brings an interesting boundary to the BVA performance and can be a limiting factor during its design, because for the BVA to work properly, the ball should roll inside the cavity. The developed models allow parametric studies to reveal areas where the BVA may lose its functionality. The successful realisation of the proposed task could provide new insights into a broader class of problems in the analysis of multibody system dynamics.

Abstract ID: 255

Parameter Identification, Reachable Workspace Analysis, and Trajectory Generation of a Tendon-Driven Soft Continuum Mechanism

Dai, Tianxiang[1]; Eugster, Simon R.[2]; Leine, Remco I.[1]
[1]University of Stuttgart, Germany; [2]Eindhoven University of Technology, Netherlands

The application of Cosserat rod theory for modeling slender mechanisms is gaining traction in soft robotics due to its balance between computational efficiency and model accuracy. Accurate modeling is critical for robot design and precise control. Here, workspace analysis is an important component, but only a few studies have been done, based on assumed material stiffness, which often leads to model inaccuracies. In this work, we present a complete pipeline for Cosserat model parameter identification,tinuum mechanism. In addition, we quantify model errors over trajectories spanning most of the reachable workspace, which are validated by experimental data. Our results demonstrate the high accuracy of the Cosserat model, except for friction effects, which could be mitigated by design refinements. The model supports workspace analysis, trajectory generation, and serves as a basis for model-based control strategie reachable workspace analysis, and trajectory generation for a tendon-driven soft cons.

Abstract ID: 257

Development of an Efficient Conformal Contact Model for Railway Applications

Nencioni, Leandro; Meli, Enrico; Cascino, Alessio; Distaso, Francesco; Shi, Zhiyong; Andrea, Rindi
Univesity of Florence - DIEF, Italy

This paper introduces a new conformal contact model for wheel-rail interaction, aimed at improving the prediction of vehicle dynamics, wear, and Rolling Contact Fatigue (RCF). Traditional models simplify wheel-rail interaction by assuming flat contact areas, but these assumptions are not valid in real-world scenarios such as curved tracks or worn surfaces, where the contact is conformal. The proposed model extends the classic Piotrowski's contact model for the normal contact problem and the FASTSIM algorithm for the tangential contact problem, allowing the analysis of non-Hertzian and curved contact pathces. Implemented in MATLAB/Simulink, the model is compatible with multibody simulations, making it suitable for low computational complexity applications. Tests on a simplified railway vehicle model showed the model's ability to accurately predict normal and tangential forces, pressure distributions, and local sliding. The model is useful for studying wear and RCF, and could be applied to real track and vehicle systems once experimentally validated.

Abstract ID: 259

Machine Learning Aided Modelling of Mechanical Systems

Merino-Olagüe, Mikel[1,2]; Plaza, Aitor[1]; Iriarte, Xabier[1,2]
[1]Department of Engineering, Public University of Navarre (UPNA), Campus de Arrosadía, 31006 Pamplona, Navarre, Spain; [2]Insitute of Smart Cities (ISC), Public University of Navarre (UPNA), Campus de Arrosadía, 31006 Pamplona, Navarre, Spain

This work introduces a novel methodology to model mechanical systems with partially known physics by integrating physical laws and Neural Networks (NN). The approach enhances traditional models by compensating for unmodeled or unknown phenomena through a combination of physical laws and

machine learning techniques. The framework optimizes both physically meaningful parameters, such as inertia and damping coefficients, and NN parameters, enabling tasks like numerical integration, model linearization, and system design. The methodology is demonstrated with two cases: a numerical example involving a Duffing oscillator with an unknown non-linear spring and a real-world energy harvesting device with unmodeled magnetic interactions. In both scenarios, the models achieve high accuracy and generalization after cross-validation, successfully recovering physical parameters and predicting system behavior under new conditions. Both models could be numerically integrated and linearized for prediction and analysis purposes. This methodology provides an effective tool for modeling, analyzing, and designing mechanical systems, offering insights into their behavior and enabling performance improvements through parameter adjustments.

Abstract ID: 260

A Modal-Based Approach for the Dynamics of Spur Gears

Serafino, Simone; Fanghella, Pietro; Verotti, Matteo
Department of Mechanical, Energy, Management and Transport Engineering, University of Genoa

Spur gear dynamic simulation represents a significant computational challenge with considerable scientific and technological implications. The evaluation of complex and specific design variations in a virtual environment is crucial in reducing the development time and cost. Previous contributions proposed simplified approaches based on lumped modeling of tooth flexibility, on model order reduction, and on single DoF systems. Generally, the presented models proved to be accurate and numerically efficient, providing user-friendly implementation. On the other hand, most of them cannot capture the dynamics effects due to manufacturing errors or to tooth profile modifications. Finite element analysis (FEA) can be considered as a possible tool to take into account these sources of error. However, it is computationally impractical in dynamic conditions because of the large amount of DoFs involved. In the present work, a novel method based on modal representation of tooth deformation is presented. According to the proposed approach, the efficiency of multibody models is combined to the tooth flexibility obtained by FEA. The modal analysis leads to a reduction of the system complexity, avoiding the introduction of fictitious visco-elastic components.

Abstract ID: 262

Development of a Log Crane Based on Flexible Multibody Dynamics and Ultrahigh-Strength Steels

Keränen, Lassi-Pekka; Ikäheimo, Eero; Walica, Dominik; Kurvinen, Emil
University of Oulu, Finland

The study explores the development of a log crane using flexible multibody dynamics and ultrahigh-strength steels (UHSS). The goal is to enhance the crane's performance by leveraging UHSS's higher yield and ultimate strengths, which allow for lighter structures and increased load capacity. The research involves simulating the log crane in two scenarios: one using general structural steel S355 and the other using S960-grade UHSS. The simulations, conducted in Siemens NX software, assess high-stress areas and fatigue resistance. Preliminary results indicate that UHSS can reduce the weight of load-bearing structures while maintaining or improving fatigue resistance. The study highlights the potential for UHSS to achieve up to 35% weight savings and better load-bearing efficiency, contributing to fuel economy and environmental sustainability. The iterative development process combines material selection, geometry optimization, and dynamic stress simulation to ensure adequate fatigue lifetime and performance improvements.

Abstract ID: 264

Development of a Wheel-Rail Wear Model Under Conformal Contact Conditions

Distaso, Francesco; Nencioni, Leandro; Cascino, Alessio; Meli, Enrico; Rindi, Andrea
University of Florence, Italy

This paper develops an innovative wear model for wheel-rail contact, addressing the challenges proposed by conformal contact conditions. Traditional models, such as the FASTSIM algorithm, rely on assumptions of flat and elliptical contact areas, which are not applicable to more complex situations. The proposed model incorporates conformal contact assumptions, capable of accurately predicting profile changes. The model is implemented in MATLAB/Simulink and interacts with a multibody vehicle model via the Simpack co-simulation solver. The wear block consists of three phases: contact model, wear model, and profile updating procedure. The test case used corresponds to a typical Italian metropolitan context and it is validated by comparing the results with experimental data. The results indicate localized wear in the tread area, with less wear on the flange side. The model proves effective in accurately evaluating profile evolution and demonstrates speed for use in real-world multibody applications.

Abstract ID: 265

On the Regularization of the Coulomb Friction Force Model Using Sigmoid Functions

Novais, Francisco[1]; Marafona, Joao[2]; Silva, Miguel[3]; Flores, Paulo[1]; Lankarani, Hamid[4]
[1]University of Minho, Portugal; [2]University of Porto, Portugal; [3]University of Lisbon, Portugal;
[4]Wichita State University, USA

The Coulomb friction force model is often expressed as a force that acts in the opposite direction of the sliding velocity of the contacting surfaces. The magnitude of this force is evaluated as the product of the coefficient of friction and the normal contact force, and is independent of the relative tangential velocity. From the implementation point of view, the Coulomb model has some weaknesses, such as the lack of an explicit constitutive law for sticking regimens, which eventually lead to some numerical and computational difficulties when the sliding velocity is zero, or in the vicinity of zero. A typical procedure to overcome these drawbacks involves regularizing the friction force during sticking scenarios. This work examines several sigmoid functions utilized to regularize the Coulomb force model, where the force is smoothened considering continuous functions expressed in terms of the sliding velocity. The classical one degree-of-freedom mass-spring system is considered as an application example, allowing the examination of the effectiveness of different sigmoid functions in regularizing the Coulomb friction force model.

Abstract ID: 266

Integration of Fatigue Analysis in the Structural Optimization of Railway Vehicles Components: Development and Application of a New Methodology

Cascino, Alessio; Nencioni, Leandro; Tafa, Idriz; Distaso, Francesco; Meli, Enrico; Rindi, Andrea
Università degli studi di Firenze, Italy

Rolling stock manufacturers are striving to minimize the environmental impact of railway vehicles, which are among the most vital solutions for mass transportation worldwide, including in emerging countries. Innovations in structural design and traction systems are the two primary areas of focus. Concentrating on the former, lightweight vehicle design plays a key role in reducing energy consumption during operational use. In order to achieve this ambitious goal, structural optimization processes can provide valuable support in the development of innovative components for the railway sector. The available literature shows that few studies have been conducted on optimization processes, particularly those applied to the bogie frames of railway vehicles. Bogies represent the most critical component of a railway vehicle due to the complex loading conditions they are subjected to during the vehicle running. Then, the possibility to actively monitor the fatigue performance of the component during its development can be crucial for the success of the design process. This work specifically focused on developing a automatic methodology capable of tracking such performance during a structural optimization process.The procedure was carried out on a bogie frame designed for a metro vehicle. The quality of the optimization process results has shown significant improvements.

Abstract ID: 269

Analysis of the Dynamic Response of an Industrial Tow Tractor Through Multibody Simulations

Fidanza, Francesco[1]; Pinelli, Marco[1]; Roychoudhury, Arka[2]; Rivola, Alessandro[2]; Troncossi, Marco[2]; Martini, Alberto[2]
[1]Toyota Material Handling Manufacturing Italy; [2]DIN - Department of Industrial Engineering, University of Bologna, Italy

This work investigates the dynamic response of a stand-on industrial tow tractor. The final goal is developing a multibody-based simulation tool capable of estimating reliably the vibration levels transmitted by the vehicle to its operator. Experimental tests are conducted on the tow tractor to measure the vertical accelerations experienced at the front and rear axles and on its floating platform when running at constant velocity over an obstacle, which is one of the most critical maneuvers in the manufacturer's testing protocols. A multibody model of the complete vehicle is developed through commercial software. A simplified model of the operator is also included, to reproduce the response of the human body to the transient perturbation induced by the obstacle, which significantly affects the platform response. Modal updating is performed by adjusting the parameters of the contact functions adopted for the ground/wheels and platform/feet interactions. The updated model satisfactorily matches the experimental signals in terms of peak amplitudes and trend of the accelerations.

Abstract ID: 271

Trim Turnpike Property for Mechanical Systems with Symmetries

Maslovskaya, Sofya[1]; Ober-Blöbaum, Sina[1]; Flaßkamp, Kathrin[2]; Wembe, Boris[1]
[1]Paderborn University, Germany; [2]Saarland University

The turnpike phenomenon, originating in economics, describes solutions in optimal control problems (OCPs) that stay close to a specific trajectory, or turnpike, for most of the time horizon, except at the beginning and end. In this work we investigate a new class of optimal control problems (OCPs) namely OCPs with symmetries (abelian and non-abelian) in relation with the turnpike property. For this class, we derive a state-adjoint exponential trim turnpike for symmetric OCPs with free final conditions. The key idea to obtained this results involves (i) applying geometric reduction to simplify the problem, (ii) proving the exponential turnpike theorem for the reduced system, and (iii) recovering the trim turnpike using group symmetries. Finally to illustrate our finding, we consider a rigid body system with rotors as a case study.

Abstract ID: 272

Twisted Wire Strands Under Coupled Loading - Experiments and Simulations

Hawwash, Muhannad; Dörlich, Vanessa; Schneider-Jung, Fabio; Linn, Joachim
Fraunhofer Institute for Industrial Mathematics ITWM, Germany

Cable and cable bundle structures are essential components of automotive applications, providing significant functionality for electrical systems and communication networks. Depending on the specific application, they vary from single conductors to unshielded twisted pairs and complex wiring harnesses. In manufacturing processes and during their lifetime, cables are often subjected to coupled loading conditions which define their three-dimensional shape. For such flexible slender structures, bending and torsion are the load cases of main interest. It is important to understand the interplay between the different deformation modes and to identify the resulting coupling characteristics. Previous experimental work for uncoupled loading has shown, that the effective mechanical response of cable-like structures is usually strongly non-linear and inelastic with pronounced hysteresis in bending. This work aims at a deeper understanding of bending-torsion coupling of twisted structures such as unshielded twisted cable pairs or twisted wires in cable conductors. Therefore, experiments and accompanying FE simulations on twisted structures will be performed. Load cases include bending, torsion and coupled loading.

Abstract ID: 273

Higher Order Model Reduction with a Mixed Formulation for Large Deflection Mechanisms

Dwarshuis, Koen; Nijenhuis, Marijn
University of Twente, Netherlands, The

The multibody simulation of complex mechanisms can be time consuming, limiting the application of numerical design optimization and model-based control. Model order reduction can be applied to reduce simulation time. In case of geometric nonlinearities – that typically occur in case of large

deflection – the widely available linear model order reduction methods are not sufficiently accurate. While nonlinear reduction methods exist, they typically depend on a priori obtained (simulation) data, making the resulting model sensitive to the chosen dataset. Another challenge the selection of a suitable set of modes. In this work, both disadvantages are addressed. A higher order model is analytically obtained using the derivatives of the element stiffness matrices in the model. A suitable set of mode shapes is chosen by distinguishing the actuation directions of the system (i.e. the intended motions of the system) from the supporting directions. The master coordinates of the model are chosen to be the displacements of the actuation directions and elastic forces for the supporting directions. The result is a mixed multibody formulation, which is a natural extension of the generalized strain formulation. Application of the method on flexure-based mechanisms shows that a third order reduced model gives representative results.

Abstract ID: 275

Study on Multibody Analysis of Posture Control for Fall Prevention

Kim, Hunhee[2]; Jung, Soonmoon[1]; Kim, Jaemin[1]; Lee, Youngho[1]; Song, Hyeyeong[1]; Oh, Seungyun[1]; Jang, Jiwoo[1]; Na, Inyeop[1]; Lee, Taekyeong[2]; Hong, Junghwa[1]

[1]Department of Control and Instrumentation Engineering, Korea University, 2511 Sejong-ro, Sejong-si, Republic of Korea; [2]R&D Center, BNR, 2511 Sejong-ro, Sejong-si, Republic of Korea

As the global population rapidly ages, falls have become a primary safety concern for older adults as well as individuals with compromised gait. They can lead to significant injuries and impose substantial limitations on daily living, underscoring the need for proactive fall-prevention strategies. This study employs a Multibody System Dynamics (MSD) approach, constructing a lower-limb model based on an Inverted Pendulum framework to more accurately represent joint behavior and ground reaction forces during gait. By incorporating springs and dampers at the knee joint, the model accounts for both elastic restoring forces and damping effects, offering a more realistic dynamic profile than traditional simplified models. Simulations in MATLAB show that the proposed method captures knee angle variations effectively throughout the gait cycle, reflecting critical biomechanical characteristics linked to fall risk. The results suggest that this Inverted Pendulum-based model can enhance the precision and practical utility of fall risk analysis, enabling early detection of gait instability and informing countermeasures for preventing debilitating falls. By facilitating the comparison of simulated results with experimental data, it can further refine predictive capabilities for targeted interventions.

Abstract ID: 276

Efficient Identification of Dynamic Systems: Combining SINDy and Mechanical Knowledge

Plaza, Aitor; Merino-Olagüe, Mikel; Iriarte, Xabier
Public University of Navarre, Spain

In this paper we present an effective methodology for identifying dynamical systems that combines the Sparse Identification of Nonlinear Dynamical systems (SINDy) algorithm along with the knowledge from multibody dynamics. SINDy is a data-driven modelling technique that can derive interpretable and generalisable differential equations which describe the dynamics of certain system. While traditional SINDy approaches are based on "brute force" generation of the so-called candidate functions, this work incorporates mechanical knowledge that will improve its efficiency and accuracy.

Some of the most important improvements are ensuring dimensional consistency, exploiting system symmetries, and using the kinematic structure of multibody systems. These modifications could reduce the search space, improve computational efficiency and maintain physical consistency. The proposed methodology is tested on various mechanical systems and its ability to accurately identify the dynamic equations even in the presence of noise is demostrated. This work contributes to the application of SINDy in multibody dynamics making it a powerful tool for system identification in mechanical engineering.

Abstract ID: 278

Stiffness Control for Inherently Compliant Robots Equipped with Active Magnetic Gears

Kordik, Thomas[1]; Gattringer, Hubert[1]; Müller, Andreas[1]; Puchhammer, Gregor[2]
[1]Johannes Kepler University Linz, Austria; [2]COBOT Dynamics gmbh

In human robot interaction (HRI) tasks the safety of the user is of utmost importance. Here, ISO TS/15066 norm defines necessary guidelines that need to be followed, e.g. maximum permissible speeds and forces that may act on individual body parts in case of contact. A way to address this issue is the use of inherently compliant robots. In this contribution, we present a two-arm robot prototype consisting of two identical links and base mounted motors which are equipped with active magnetic gears. The transmissible torque of a prototype of the compliant gears over its relative angle follows a sinusoidal characteristic curve. If the maximum gear torque is exceeded, e.g. due to contact with the environment, the gearbox disengages. Furthermore, the magnetic field inside the gearbox can be either demagnitized or saturated by a coil installed in the gearbox, which means that the compliance and maximum torque of the gearbox can be controlled almost instantaneously. This mode of operation makes it possible to reduce the reflected mass and inertia of the mechanism and thus provides a certain safety aspect. Exemplarily, the modeling and control of the first link are derived and results of an energy-optimal pick&place operation are shown.

Abstract ID: 279

Development of a Hybrid Mooring Line Model Based on the Incremental Form of Finite Rotation

Hara, Kensuke
Central Research Institute of Electric Power Industry

Offshore wind energy is the key to the transformation of the global energy structure. In particular, the floating offshore wind turbines are appropriate for development in a sea area with water depths oof deeper than about 50 m. On the other hand, the cost of stationkeeping systems for the floating wind turbines tends to increase with water depth. Therefore, techniques for stationkeeping system components have seen increasing interest as ways to reduce floating wind farm costs, such as hybrid mooring systems and shared mooring systems. This study deals with a structural modeling for the hybrid mooring lines comprised of segments with elastic ropes and chains. In the present mooring line model, the chain segments are modeled as multi-rigid bodies, and the nonlinear finite element beam model based on the ANCF consistent rotation based formulation is introduced for the rope segment. Then, we discuss dynamic behavior depending on anchored and shared mooring line configurations.

Abstract ID: 280

The Applicability of Magnetorheological Elastomers in Suspension Systems for High-speed Train

Shin, Yu Jeong
KRRI(Korea Railroad Research Institute), Korea, Republic of (South Korea)

Recently, when designing a bogie considering various operating conditions, research on intelligent vehicles using smart materials is being actively conducted rather than adding complex mechanism control devices to existing railway vehicles. Magneto-rheological elastomers (MRE) are smart materials that can change their stiffness and damping characteristics in response to external magnetic fields. In this study, in order to apply magnetorheological elastomers to rubber material parts of railway vehicles, various types of materials and new types of specimens were produced and their properties were tested to confirm the possibility of variable stiffness. A high-speed railway suspension element joint using variable stiffness materials was produced and its performance was confirmed. The research results confirmed that further research is needed, such as the effect of temperature generated when current is applied to a variable stiffness suspension device and the design of a new mechanism for this. Therefore, it seems that more in-depth research on the matrix, magnetic particles, manufacturing process, and mechanism implementation will be needed until it is actually manufactured as a railway vehicle component.

Abstract ID: 281

Microgravity Experiments for Contact Dynamics Characterization in the Asteroid Environment

Vaghi, Samuele; Cremasco, Alessia; Delfanti, Luigi Vittorio; Fodde, Iosto; Ferrari, Fabio
Politecnico di Milano, Italy

Most asteroids are thought to be aggregates of loosely consolidated material. This granular nature suggests that they can be effectively simulated with N-body codes, such as GRAINS, that exploits Chrono libraries to handle contact dynamics. Although its capabilities to model large-scale asteroid evolution scenarios have been demonstrated, it is an open point to validate its capability to represent local-scale contacts. To fill this gap, a microgravity experimental campaign has been performed in the context of the ERC-funded project TRACES, consisting in sixteen tests at the ZARM facilities. The goal was to observe the collision between asteroid simulant cobbles and reconstruct their full-state motion with cameras. A digital twin was developed with the purpose of tuning the contact models and parameters to fit at best the experiment's results. This work describes the realization of the experiment, including the description of the setup and the analysis of the outcomes. The campaign can be considered successful: the outcomes are expected to greatly improve our capabilities to model rubble-pile asteroids, with beneficial effects for both scientific studies and design of future asteroid exploration missions.

Abstract ID: 282

Refining Contact Force Models for Energy Dissipation Modelling in Multibody Dynamics

Warzecha, Mariusz
AGH University of Krakow, Poland

Precise modeling of energy dissipation during collisions is crucial for accurate multibody dynamic simulations. Traditional contact force models, such as those based on the Hunt and Crossley formulation, rely on a constant damping coefficient derived from a fixed coefficient of restitution (CoR). However, experimental data reveal that the CoR varies significantly with the initial collision velocity, limiting the accuracy of these models. This work introduces an enhanced contact force model that accounts for the variation of energy dissipation with collision velocity. The model incorporates a CoR as a function of the collision energy dissipation velocity, enabling a better representation of energy losses in scenarios with both non-zero and zero initial relative velocities. Implemented in Python, the proposed model was validated through simulations of bead chain collisions with velocities ranging from 0.1 to 3 m/s. Comparative results, including finite element method (FEM) benchmarks, demonstrate improved post-impact velocity predictions. The improvements depend on the initial collision velocity and the number of beads in the chain. The proposed model improves the modeling of energy dissipation in collisions and is suitable for modeling collisions initiating with zero relative velocity.

Abstract ID: 283

A Novel Frictionless Contact Method for Planar Flexible Bodies

Maddio, Pietro Davide; Cammarata, Alessandro; Sinatra, Rosario
University of Catania, Italy

This work introduces a novel frictionless contact method designed for planar flexible bodies, employing the penalty approach to calculate contact forces. Unlike conventional methods that rely on meshing techniques, this method directly evaluates the intersection area between bodies, which serves as the basis for computing the contact force. The force is distributed among the nodes of the bodies to ensure that the sum of the nodal contributions matches the resultant of the main contact force vector and accurately represents local deformations caused by the interaction. Numerical comparisons with segment-to-segment methods demonstrate equivalent results, showcasing the robustness and reliability of the proposed approach. This innovative method offers a promising solution for simulating contact interactions in planar mechanisms with high precision.

Abstract ID: 284

Energy-Saving Control of a Robot Manipulator with Biarticular Muscle-Like Springs Imitating the Human Upper Limbs

Dozono, Chikako; Tanizaki, Kenshu; Iwamura, Makoto
Fukuoka University, Japan

In this study, we examin the energy-saving control of a robot manipulator equipped with springs equivalent to mono-articular and bi-articular muscles, mimicking the human upper limbs. First, we use a multibody dynamics method to derive the equations of motion for a manipulator equipped with springs. We then discuss the energy-saving control problem, dividing it into Point to Point (PTP) control and Continuous Path (CP) control. For the PTP control problem, we use optimal control theory to analytically derive the optimal trajectory, control input, spring constant, and spring mounting angle. We also clarify the existence of an optimal operating time and propose an optimal design method for the springs. On the other hand, we show that the CP control problem can be reduced to a problem of optimizing only parameters such as the spring constant and the spring mounting angle, and propose a method to search for the optimal parameters using particle swarm optimization. The effectiveness of the proposed method is verified by numerical simulations.

Abstract ID: 285

Identification of Friction Forces Within Two Types of Planar Absorber Mechanisms

Kraus, Karel[1]; Kočandrle, Petr[2]; Šika, Zbyněk[1]
[1]Faculty of Mechanical Engineering, Czech Technical University in Prague, Czech Republic; [2]Amadeus Czech Republic & Slovakia, Czech Republic

For all joints in various complex mechanisms, such as planar vibrational absorbers, there can be variety of passive effects. When designing multi-DoF absorber mechanism, a great effort must be made in the constraints design and bearing type selection in order to mitigate passive effects as much as possible. However, even very precisely designed structures must be assumed to incorporate more complex friction then a mere viscosity. In this work, a sequence of models have been created and tested for each device passive effects description. Initial linear model was followed by extended smooth Coulomb function sufficient for the case of symmetrical case of absorber demonstrator. This sequence was followed by dynamical LuGre model later layered with additional neural network model to be able to describe vast nonlinearities present in constraints in the case of perpendicular absorber design.

Abstract ID: 286

Vibration Absorber Actively Converted to Mechanism with Minimal Frictional Effects

Šika, Zbyněk[1]; Kraus, Karel[1]; Vyhlídal, Tomáš[1]; Michiels, Wim[2]
[1]Czech Technical University in Prague, Faculty of Mechanical Engineering, Czech Republic; [2]KU Leuven, Department of Computer Science, Belgium

Vibration absorbers are greatly able to suppress vibrations of robots and machines in order to increase their accuracy or speed. Compared to other methods, such device can work in challenging conditions, and for optimal operation it must be designed as much as an ideal absorber as possible,

i.e. to achieve frictionless state. A procedure was implemented by simulation and then experimentally, where the proposed planar vibration absorber mechanism was brought closer to a state with very low frictional and generally dissipative forces using active forces generated in controlled voice-coils. It turned out to be necessary to thoroughly optimize the mechanical design of the mechanism so that the initial dissipative forces are as small as possible and well predictable. Thanks to this, relatively simple voice-coil control laws derived from the identified models of friction forces were sufficient for significant active minimization of dissipation. Identification and testing of the active control itself were successfully implemented on the demonstrator, which was then used to test the absorption function.

Abstract ID: 287

Adjoint Gradient Computation for an Extremal Value of a System Output

Zallinger, Philipp[1]; Lichtenecker, Daniel[2]; Eichmeir, Philipp[1,3]; Steiner, Wolfgang[1]; Nachbagauer, Karin[1,4]
[1]University of Applied Sciences Upper Austria, Austria; [2]TUM Technical University of Munich; [3]Vienna University of Technology; [4]Institute for Advanced Study, TUM Technical University of Munich

The present work illustrates the derivation of an adjoint gradient for an extremal value of a system output of a non-linear dynamic system, as e.g. the maximum occurring joint reaction force in the dynamics of a multibody system. Therefore, the objective is defined by the extremal value and the goal is to find an efficient and accurate gradient information for an advanced update in classical gradient-based optimization strategies. Hence, the gradient of the objective is derived here by using the adjoint method following the basic idea tracing back to Bryson and Ho. The presented adjoint gradient computation will be applied in two examples. An academic example of an one-mass oscillator shows the easy applicability and a more complex application of a two-arm robot will show the use-case for a multi-objective optimization scenario.

Abstract ID: 288

Multibody Dynamic & Aerodynamic Modeling of a Tube-Launched Sweep Morphing Unmanned Aerial System

van Elsloo, Samuel Johannes[1]; van Rooij, Michel[2]; Hamraz, Ash[2]; De Breuker, Roeland[1]; Voskuijl, Mark[3]
[1]Delft University of Technology, The Netherlands; [2]Royal Netherlands Aerospace Centre, The Netherlands; [3]Netherlands Defence Academy, The Netherlands

In recent years, tube-launched unmanned aerial systems (UAS) with sweep morphing lifting surfaces have grown in popularity. Such systems, particularly when launched in-flight from a larger aircraft, exhibit strong coupling between the structural dynamics, aerodynamics and flight dynamics due to its multibody dynamics. In existing literature, frequently, high fidelity aerodynamic simulations are coupled with a prescribed flight path; free-flight models are often coupled with lower fidelity aerodynamic models. Thus, a mid-fidelity aerodynamic model, based on an unsteady panel method, was coupled with a multibody model, to quantify the strength of the interaction. First, the aerodynamic model is compared to an URANS-based CFD simulation, establishing its suitability to model such UASs. Then, the coupled model is applied to a free-flight simulation. The motion induced by the relative motion of its own lifting surfaces is found to affect the pitch angle by several degrees over

a short deployment period. Inclusion of the aerodynamic and gravitational forces introduces affects the attitude of the UAS at the end of the motion to a similar degree. Furthermore, the angle of attack may vary by several degrees during the deployment, stressing the need to include the flight dynamic motion in the modeling of such systems.

Abstract ID: 289

Optimization-Based Identification of Low-Dimensional Port-Hamiltonian Systems

Rettberg, Johannes[1]; Sharma, Harsh[2]; Fehr, Jörg[1]; Krämer, Boris[2]
[1]University of Stuttgart, Germany; [2]University of California, San Diego, USA

Modern markets require rapid product development cycles and optimized designs that integrate multiple physical domains, posing challenges like multiscale effects or modular coupling. Port-Hamiltonian (pH) systems offer a promising solution, using energy at the heart of a universal modeling framework. These systems ensure energy dissipation, i.e. passivity, facilitating dynamic system analysis and automated modeling. The work focuses on identifying low-dimensional linear pH systems from time-domain data, addressing limitations in existing methods. Traditional approaches often use standard Proper Orthogonal Decomposition (POD) for dimensionality reduction or require frequency-domain transformations or knowledge of the Hamiltonian gradient. This study explores alternative reduction methods and optimization-based identification directly from time-domain data without these constraints. Innovations include using energy-focused data reduction techniques, such as energy-norm POD (ePOD) and symplectic decomposition, improving accuracy over standard POD. Optimization algorithms, such as semidefinite programming and fast gradient methods, that simultanously ensure compliance with pH constraints like skew-symmetry and passivity through the Kalman–Popov–Yakubovich inequality. Case studies, including a mass-spring-damper chain and a multiphysics guitar model, demonstrate the proposed approach's effectiveness.

Abstract ID: 290

An Analytical Method for Planar Motion of Rigid-Plastic Bodies Undergoing Plastic Deformation and Contact Based on the Linear Complementarity Problem

Misaizu, Yuki[1]; Sugawara, Yoshiki[2]; Takeda, Masakazu[2]; Kitazawa, Yuki[1]
[1]Graduate School of Science and Engineering, Aoyama Gakuin University; [2]Aoyama Gakuin University

Plastic deformable materials have attracted attention as materials for shock absorption systems in vehicles, spacecraft and so on. Understanding the behavior not only during deformation at the time of impact but also after deformation is crucial. However, conventional finite element methods require immense computation time. As a result, optimization design becomes very time-consuming and extremely difficult, and promising analysis method for such motion is strongly required. Our research group has already proposed an efficient formulation method for the behavior where both contact and plastic deformation occur simultaneously for plastic deformable materials undergoing one-dimensional deformation, using Linear Complementarity Problems (LCP). But one-dimensional motion is not enough for practical application. Therefore, in this study, we propose an efficient motion analysis method for planar motion of objects experiencing plastic deformation and contact involving friction, using LCP. The proposed method was applied to a simple basic model, and motion evaluation was conducted through numerical analysis to demonstrate the validity of the proposed method.

Abstract ID: 291

Development of a Fast Spring Drive Using Multi-Body Simulation

Gerlach, Erik Rainer; Zentner, Lena
TU Ilmenau, Faculty of Mechanical Engineering, Germany

This thesis deals with the development and investigation of a fast spring drive. The task of the actuator is to move a mass a certain distance in the desired time. One example of the particularly high demands placed on spring drives is their use in electrical switching devices. Here, the required expansion speed is close to the physical limit. The simplified approach of considering 1/3 of the spring mass in the dynamic calculations leads to large deviations here due to the mass ratios. Therefore, a multi-body simulation model was created that better reflects reality. To validate the model, an experimental setup was built and the real movement was measured.

Abstract ID: 292

Stress Recovery Based on Linearized Flexible Multibody System Equations

Held, Alexander; Seifried, Robert
Hamburg University of Technology, Germany

The method of flexible multibody simulations is well-established to model and analyze mechanisms and general dynamical systems, whose members undergo large nonlinear motions and deformations. The floating frame of reference formulation allows the efficient incorporation of linear elastic bodies into multibody systems since a set of shape functions approximates their deformations. If the number and choice of the deformation and corresponding stress modes are chosen properly, the deformations and stress field can be approximated accurately. However, for special cases, such as in topology optimization with stress constraints, the number of elastic degrees of freedom is limited due to the computational burden in the primal simulation and sensitivity analysis. Thus, to increase the efficiency in these special cases, the stresses are recovered alternatively from the linearized equations of motion of the flexible multibody system in this work. At first, a flexible nonlinear multibody simulation is performed, in which a comparatively small number of elastic coordinates describes the elastic deformations. Then, the number of elastic degrees of freedom is increased, and the system equations are set up and linearized around the trajectories of the nonlinear model. Based on this linear analysis, the stresses of the flexible bodies are efficiently recovered.

Abstract ID: 293

Application of Servo-Constraints to Model Inversion of Port-Hamiltonian Systems

Hochdahl, René Christopher; Seifried, Robert
Hamburg University of Technology, Germany

The port-Hamiltonian approach is a port-based modeling technique that breaks down a system into its core components and describes the energy flow between them. Each component interacts with the system via a port consisting of two dual quantities, flow and effort, whose product constitutes the power flow into the element, e. g. velocity (flow) and force (effort). This modular modeling approach,

which is especially useful for large network-like systems, yields a unified mathematical formulation. Controller design with the port-Hamiltonian modeling approach often utilizes energy-based control strategies. However, model inversion for trajectory tracking of port-Hamiltonian systems has only been investigated for a small amount of systems with a direct feedthrough. This contribution focuses on the inversion of systems without direct feedthrough as is usually the case for multibody systems. For this, the straightforward approach of formulating servo-constraints to force the output to follow a desired trajectory is chosen. This approach is demonstrated for the inversion of selected underactuated systems and its difference to model inversion applied to classically modeled multibody systems is discussed.

Abstract ID: 294

Towards a Quasi-Static ALE-frictional Formulation for Cable-Actuated Multibody Systems

Devigne, Olivier; Brüls, Olivier
University of Liège, Belgium

This work presents a quasi-static arbitrary Lagrangian-Eulerian (ALE) model for frictional contact in cable-actuated multibody systems. The model accounts for frictional interactions between a cable, treated as a geometrically exact beam, and rigid bodies like pulleys or sleeves in a quasi-static setting. Friction is described using Coulomb's law following an augmented Lagrangian approach to consider stick-slip phenomena. The ALE framework allows cable nodes in the contact region to remain spatially fixed with respect to the interacting body, while allowing material flow. This approach avoids the fine discretization of the contact-free cable span. A preliminary result is proposed, consisting of a cable sliding in a sleeve, highlighting the ability to capture the stick-slip behavior. These results mark a first step towards a general framework for simulating frictional contact in cable-actuated systems.

Abstract ID: 296

A Novel Time-Stepping Approach for Mechanical Systems

Solanillas Francés, David Manuel; Kövecses, József
McGill University, Canada

The nonsmoothness introduced by unilateral contact in the dynamics of mechanical systems typically requires time-domain simulations to be performed through time-stepping discretization. In this context, a new time-stepping method for mechanical systems is proposed. The method uses a maximal-velocities representation for the dynamics and a minimum-velocities representation for the configuration update. With the maximal-velocities representation, the nonlinear inertial terms have simple expressions, allowing us to easily treat them in an implicit way, improving the stability of the numerical method. In this representation, the bodies of the system are treated as separate entities connected by kinematic joints, which are modelled by constraint equations. At the velocity level, such constraint equations are linear and can be fully satisfied. However, at the position level, additional techniques are required to enforce the constraints. The representation with minimum velocities is used to address this issue since the kinematic joints are already integrated into the equations of motion, thereby eliminating the need for separate constraint equations.

Abstract ID: 297

A Total Lagrangian Mixed Petrov–Galerkin Cosserat Rod Finite Element Formulation

Herrmann, Marco; Eugster, Simon R.
Eindhoven University of Technology, The Netherlands

This work presents an objective, locking-free and computationally efficient Cosserat rod finite element formulation that can be seamlessly integrated into existing multibody frameworks. The computational complexity of multibody system increases dramatically with the inclusion of flexible components, like Cosserat rods. The complexity arises not only from the highly nonlinear and coupled interpolation of the position and orientation fields, but also from the nonlinear calculation of strains and stresses based on the previous quantities. Additional challenges are posed by numerical effects leading to membrane or shear locking and the general need for an objective interpolation. To overcome these challenges, different strategies exist. These strategies often introduce more unknowns, like redundant coordinates, or make the computations more complex. This work combines mainly two different strategies. At the first hand, a simple, yet objective, interpolation of the cross-section orientations using non-unit quaternions and at the second hand a mixed approach for the internal stresses. Applying a Petrov–Galerkin projection method leads to the equations of motion of the discretized rod.

Abstract ID: 298

On Coupling Effect of Variables in Contact Force Laws

Antali, Mate
Szechenyi Istvan University, Hungary

Friction models in multibody systems are often phenomenological models which contain the resultant effect of the mechanical behaviour in the contact. These models are usually expressed by the generalised velocities and forces at the contact. In the various sources of the literature, we can find several models related to dry friction, for example, the Coulomb friction, the Coulomb-Contensou friction, the creep force models or the contour friction. Despite the diverse properties and formulations, we can find common properties of these models. In this research, we focus on the coupling effect between the velocities in these force models. The analysis of common nonsmooth characteristics of these coupled models can be utilised for the qualitative analysis in dynamical systems of rigid bodies.

Abstract ID: 299

Robust Speed Control of Multi-Link Mechanism Using H-Infinity Optimization

Hrabačka, Martin; Goubej, Martin; Hajžman, Michal; Dyk, Štěpán; Bulín, Radek
University of West Bohemia, Czech Republic

The robust speed control of multi-link mechanisms is crucial in various industrial applications where efficiency, precision, and reliability are critical. This paper addresses the challenge of controlling inherently non-linear systems, represented by a seven-link mechanism. Using H-infinity optimization, a robust controller is designed to stabilize the system and maintain the defined velocity. The mechanism is linearized at multiple positions along the working cycle, resulting in a set of linearized models used for controller synthesis. The H-infinity framework ensures robustness and guarantees con-

trol quality. The synthesized controller, implemented in MATLAB-Simscape, demonstrates excellent performance, achieving a velocity error below 0.5 % under ideal conditions.

Abstract ID: 300

Simulating Balancing Movements of Vehicle Occupants

Harant, Monika[1]; Björkenstam, Staffan[2]; Roller, Michael[1]; Linn, Joachim[1]
[1]Fraunhofer ITWM, Germany; [2]Fraunhofer-Chalmers Centre, Sweden

Human models are an essential component in vehicle design and safety studies. Kinematic models are used for ergonomics evaluation, finite element models in crash simulations to analyze possible injuries on the occupants. Active models that allow for motion generation considering inertia effects are not yet frequently used in the design process of vehicles although they could offer vital insights on both, ergonomics and safety. In this work, we focus on simulating occupants in vehicles that are required to compensate vehicle movements unknown to them. This scenario involves the prediction of responsive behavior, which poses a difficult requirement for the motion generation method. In previous work, we applied optimal control (OC), a promising tool for predicting various types of motions. Since OC requires to include the vehicle movements in the optimization process, it is difficult to generate a responsive behavior of the occupants. We extend the OC setup by a control loop, resulting in a method known as nonlinear model predictive control (NMPC). We show that NMPC is able to generate behavior that is not preparing for future vehicle movements but reacting to them and compare the simulation results to the ones obtained by OC.

Abstract ID: 301

A Nonsmooth RATTLE Algorithm for Mechanical Systems with Frictional Unilateral Constraints

Breuling, Jonas[1]; Capobianco, Giuseppe[2]; Eugster, Simon R.[3]; Leine, Remco I.[1]
[1]University of Stuttgart; [2]FAU Erlangen-Nürnberg; [3]Eindhoven University of Technology

In 1983, Andersen proposed the RATTLE algorithm as an extension of the SHAKE algorithm. The RATTLE algorithm is a well-established method for simulating mechanical systems with perfect bilateral constraints. Recently, the authors of this presentation further extended the scheme for simulating also nonsmooth mechanical systems with frictional unilateral constraints (i.e. frictional contact). With that it satisfies the need of higher-order integration methods within the framework of nonsmooth contact dynamics in phases where the contact status does not change (i.e. no collisions/ constant sliding states). In particular, the proposed method can simulate impact-free motions, such as persistent frictional contact, with second-order accurate positions and velocities and prohibits penetration by unilateral constraints on position level.

Abstract ID: 302

Theoretical and Computational Aspects in a Mechanical Network Model of Compliant Mechanisms

Sorgonà, Orazio[1]; Giannini, Oliviero[1]; Verotti, Matteo[2]
[1]Department of Engineering Niccolò Cusano University of Rome; [2]Department of Mechanical Engineering, Energetics, Management and Transportation, University of Genoa

Fully compliant mechanisms (CMs) are jointless mechanical systems that gain mobility through the deformations of their flexible parts. These systems are challenging to model and to design due to the coupling of their kinematic, dynamic, and elasto-mechanic features. The complexity of this problem has been addressed by a variety of models and methodologies, that proved to be effective from many points of view. However, mature definitions of comprehensive principles, models, and design strategies are key objectives for the research at the state-of-art. Generally, three different synthesis approaches can be followed, that are: a purely kinematic approach, relative to rigid-body fields of displacements, at the output port level; a continuum-based approach, limited to the synthesis of flexures, at the element level; and the Mechanical Network Model (MNM) approach at the mechanism level. The MNM, based on the graph-theoretical perspective and on the mobility analogy, generalizes to compliant mechanisms the topological approach to rigid-body linkages. In this work, the MNM is developed for compliant systems, according to the mobility analogy. An application to the modal analysis of systems with general topology is presented. Different formulations of the eigenvalues problem are compared in terms of computational time.

Abstract ID: 304

Calculating Higher-Order Time Derivatives of Rigid Multibody Dynamic Equations for Design Purposes

Meijaard, Jacob P.; van der Wijk, Volkert
Delft University of Technology

Multibody dynamics codes usually determine the second-order time derivatives, the linear and angular accelerations, based on positions, velocities and forces, either in a symbolic form or numerically. In some cases, higher-order time derivatives are needed, for instance for some numerical integration methods and for designing controllers. Here, we consider the application in the dynamic design for specific characteristics or tasks. Furthermore, time derivatives of nominal actuator torques in inverse dynamics and of reaction forces can be useful. Here, a method is used that takes derivatives of the equations in the formalism based on finite elements with generalized strains, which can be equated to zero to model rigid elements. The calculations simplify if elements with simple deformation functions and a mass description that yields constant mass matrices are used. Applications to design problems requiring the distribution of mass in mechanisms are presented.

Abstract ID: 305

Comparative Study of Two Biomechanics Frameworks for Upper Limb Exoskeleton Simulations

Moreno, Benjamin; Sonneville, Valentin; Foguenne, Léonore; Schwartz, Cédric; Sacré, Pierre; Brüls, Olivier
ULiege, Belgium

The development of wearable assistive devices calls for advanced predictive simulation tools capable of modelling musculoskeletal systems incorporating closed kinematic loops, such as upper-limb exoskeletons. This study focuses on simulating arm movement with a shoulder exoskeleton in two scenarios: a forward dynamics simulation and an optimal control problem to determine the optimal muscle excitations and motor torque inputs required for a desired motion. Two computational frameworks are employed and compared: The first is OpenSim, which benefits from existing biomechanical models and optimal control capabilities with MOCO. The second framework is Odin, a state-of-the-art multibody simulation software in which biomechanics capabilities were integrated for this study. The comparison highlights the strengths and limitations of each tool in simulating biomechanical systems with complex kinematic topologies. While results were successfully obtained in OpenSim, challenges were encountered due to the presence of kinematic closed loops. In contrast, Odin's general multibody framework simplifies the definition and numerical simulation of closed kinematic loops, demonstrating significant potential for future applications in exoskeleton design and analysis.

Abstract ID: 306

Kinematics and Motion Planning of a Breeding Blanket Transporter for Remote Maintenance of an EU Fusion Tokamak

Zhang, Xuping
Aarhus University, Denmark

The future demonstration fusion power plant EU DEMO must be maintained remotely in reasonable time to achieve safety as well as economic viability. The largest in-vessel components which will need to be replaced are the breeding blankets (BB's). Each vacuum vessel sector contains 5 BB segments: two inboard weighing 125 t each and three outboard weighing 180 t each. The BB vertical transporter (BBVT) is a crane-like robotic arm which has been previously designed at a conceptual level to remove and replace the BB segments through the upper port. It has an actuated gripper and 7 joints, which are required for grasping and manipulating the BB segments in 3D space. The BBVT was modeled as a redundant manipulator, and the inverse kinematic problem was solved analytically for cases when one joint position is known. This was applied to generate collision-free waypoints for BB segment handling in the limited confines of the vacuum vessel and upper port while minimizing static loads on the tilting joints.

Abstract ID: 307

Kinematics and Dynamics of a Cable-Driven Floating Platform for Desedimentation

Bieber, Jonas; Bernstein, David; Beitelschmidt, Michael
Chair of Dynamics and Mechanism Design, Technische Universität Dresden

This study presents the kinematic and dynamic modeling of a cable-driven floating platform for sediment removal in reservoirs. The platform is designed as a parallel cable-driven robot, allowing precise automated maneuvering. The kinematics can be seen as a planar problem. Analytical methods solve the inverse kinematics, while forward kinematics are approached numerically as an optimization problem. Dynamic modeling is based on the equation of motion, with a focus on the system inertia and the cable forces. With the system's mass matrix and the Jacobian matrix the desired translational acceleration and motor torques are mapped onto each other.

Abstract ID: 308

Determination of Parameter Sensitivity of Multibody Co-Simulation Models Using the Adjoint Method

Bortels, Daan[1,2]; Vanpaemel, Simon[1,2]; Naets, Frank[1,2]
[1]E2E Core Lab, Flanders Make; [2]Dept. of Mechanical Engineering, KU Leuven

In the design of mechatronic systems, there is an ever increasing need to gain insight into how different system parameters influence the overall performance of the system. However, due to the inherent complexity of these systems, it can be challenging to determine these influences. Mechatronic systems consist of several different interdependent components that might be modeled in different physical domains, and which are in practice solved using co-simulation techniques. Understanding how one parameter will influence each of these different models simultaneously is not a simple task. In this work, the mechatronic system is simplified for clarity to a co-simulation between a multibody model, representing the mechanical system, and an external model in the form of a 'Functional Mock-up Unit (FMU)' . The FMU is added as a computational black-box element to the co-simulation which will influence the dynamics of the multibody model. The adjoint method is considered here as the method used to determine the requested sensitivities which is due to the large number of design parameters that can be present in a multibody model. This work will show the adjoint method extended with the influences of the external FMU applied on a theoretical use case.

Abstract ID: 309

Detecting Cable Failure in Cable Driven Parallel Robots Through Deep Neural Network Classifiers

Bettega, Jason; Richiedei, Dario; Trevisani, Alberto
University of Padova, Italy

This paper discusses the issue for cable failure identification in Cable Driven Parallel Robots (CDPR) by exploiting deep neural network classifiers and the estimated motor load torques. This problem has ha practical and theoretical interest since cables in CDPR can failures under excessive stress of because of fatigue, by seriously compromising the operation of the robot and leading to hazardous

situations. The method proposed in this paper is based on two macro steps: first, an open-loop load torque observer, that computes the estimated load torque for each motor; second, a supervised classification algorithm based on neural network, aimed at identifying failure through such estimated load torque. The load torque observer exploits dynamics model of each actuator in the conditions of no load and current and position measures provided by the motor drive; this choice makes the estimation robust with respect to uncertainty on the model of the cable and the end-effector. As for the classifier, to handle the temporal characteristics of data, recurrent neural networks are adopted. Numerical validation is provided.

Abstract ID: 311

Comparative Analysis of Programming Languages for Multibody Dynamics with Contact Events: Matlab vs. Julia

Gismeros Moreno, Raúl[1,2]; Corral Abad, Eduardo[1,2]; Gómez García, María Jesús[1,2]; Castejón, Cristina[1,2]
[1]Universidad Carlos III de Madrid, Spain; [2]Instituto de Desarrollo Tecnológico y Promoción de la Innovación Pedro Juan de Lastanosa, Universidad Carlos III de Madrid

Multibody Dynamics (MSD) is a versatile methodology used for optimizing designs and reducing costs across product lifecycles. MSD simulation tools can be classified according to their physical location, licensing, or application, with commercial tools emphasizing user-friendliness and "in-house" solutions providing customization and flexibility. Recent trends favour open-source programming languages like Python and Julia. The latter has gained particular popularity lately due to its efficiency and ease of use in numerical analysis and machine learning. This study focuses on adapting an "in-house" MSD tool originally developed in Matlab, to Julia. Julia's library for Ordinary Differential Equations (ODEs) stands out for its high level of optimisation and modification, which is particularly of interest in scenarios involving multiple-simultaneous contact events. Three test models that made use of different features generally present in multibody systems were defined to compare Julia's performance against Matlab's. The port from Matlab to Julia involved the modification of global variables definition and scripts to align with Julia's own characteristics. Critical calculations, such as Newton-Euler equations and contact force evaluations, were carefully reimplemented to ensure both accuracy and efficiency. While Julia's library provided substantial improvements in critical bottlenecks identified in Matlab's version, further optimization of post-processing scripts is still required.

Abstract ID: 312

Simulation of Multibody Systems with Switching Constraints: Formulation and Time Integration

Patil, Indrajeet; Brüls, Olivier
University of Liège, Belgium

In multibody dynamics, it is often assumed that bilateral or two-sided constraints satisfy sufficient continuity and differentiability conditions. This does not necessarily hold, as conditional statements may also trigger abrupt changes in the algebraic constraint expressions, which are not differentiable anymore. In such situations the instantaneous switch induces a nonsmooth response with possible velocity jumps. The equations of motion of such multibody systems can be expressed in the form of switched differential-algebraic equations (DAEs), which differ both from classical DAEs and from systems with unilateral constraints. As a result, the mathematical modelling and numerical integra-

tion require a specialized treatment. The aim of this work is to present a general modelling procedure and explore nonsmooth time integration methods for multibody systems with switching bilateral constraints. Several examples illustrate the methodology and its ability to represent discontinuous transitions between modes.

Abstract ID: 313

Applicability and Effectiveness of the Bennet Mechanism

Postulka, Tomas[1]; Alwis Weerasinghe, Sachintha[2]; Orzechowski, Grzegorz[2]; Mikkola, Aki[2]; Hunady, Robert[1]
[1]VSB – Technical University of Ostrava, Czech Republic; [2]LUT University, Finland

One of the main challenges of modern engineering is to increase the efficiency and thus reduce the energy consumption of multi-body systems. Among such systems, we may include the Bennett mechanism, which is one of the simplest mechanisms with a closed kinematic structure and one degree of freedom (1 DOF). It consists of four rotary joints connected by four links forming a single loop. Despite the over-constrained mechanism, it is capable of movement, which can be practically used in industrial environments. However, the utility of this rather theoretical multi-body system is still complicated, as there are still many aspects to be resolved before it can be successfully used in industrial applications. To assess the potential of this system, a study was conducted to investigate its utility and, in particular, to measure the energy consumption in a pick-and-place application compared to commercially available robots.

Abstract ID: 315

Some Aspects in Simulation, Design and Control of Wave Energy Converters

Hollm, Marten; Seifried, Robert
Hamburg University of Technology, Germany

Nowadays, renewable energies, such as hydropower, solar, and wind energy, are playing an increasingly important role. Besides these well-known and widely applied sources of renewable energies, there is also the possibility of harvesting energy from ocean waves using wave energy converters (WEC). However, there are many technical, logistical, and economical challenges in harvesting of ocean energy. Although experiments in wave flumes with harmonic waves show promising results, so far only a very small amount of energy has been obtained from ocean waves. This is because ocean waves are highly irregular and generate only low-frequency hydrodynamic loads, making it challenging to use conventional generators for electricity production. Therefore, the use of WEC is still widely in the research and prototype phase. Applications are so far often limited to special usage cases, where other forms of energy supply are not possible. In this presentation, some aspects in modelling and simulation-based design and control of different types of wave energy converters are discussed.

Abstract ID: 317

ChronoLLM: A Framework for Customizing Large Language Models for Digital Twins Based on PyChrono

Wang, Jingquan; Zhang, Harry; Slaton, Khailanii; Wang, Shu; Serban, Radu; Wu, Jinlong; Negrut, Dan
University of Wisconsin-Madison, United States of America

This abstract presents ChronoLLM, a framework designed to produce automatically PyChrono [1] models (scripts) using large language models (LLMs) that are fine-tuned with domain-specific data. PyChrono, a Python wrapper for the open-source Project Chrono [2], facilitates high-fidelity, multiphysics simulations for applications in several areas, e.g., autonomous vehicles, robotics, granular dynamics. The complexity of PyChrono's API and its frequent updates pose significant challenges for users. ChronoLLM addresses these challenges by fine-tuning both close-source and open-source LLMs, such as GPT-4O [3] and LLaMA3 [4], to generate accurate, efficient, and user-friendly PyChrono simulation scripts. This aspect is helping the users since PyChrono has a steep learning curve. By combining AI capabilities with the versatility of the PyCHrono simulation platform, ChronoLLM can lower the user entry point while improving simulation reliability.

Abstract ID: 318

Design Evaluation of Aircraft Seat Safety Using a Plastic Hinge Multibody Model

Martins, Ana[1]; Carvalho, Marta[1]; Olivares, Gerardo[2]; Lankarani, Hamid[3]
[1]NOVA School of Science and Technology, Portugal; [2]National Institute for Aviation Research; [3]Wichita State University

To comply with safety regulations, aircraft seats must undergo dynamic testing to assess their structural performance and occupant safety. This compliance is verified by ensuring that injury parameters and seat loads remain within regulatory thresholds for transport category aircraft. In the evaluation of seat crashworthiness, numerical models serve as essential tools that facilitate the analysis of innovative materials and configurations while minimizing associated costs. This study developed a multibody model of an aircraft seat to simulate dynamic testing conditions and analyze design parameters for improved crashworthiness. Structural deformation was modeled using the plastic hinge approach. The numerical model was validated against test data, comparing occupant kinematics and verifying the correlation between simulation and experimental results. The validated model was used in a parametric analysis aimed at reducing seat weight while ensuring compliance with safety standards. The model demonstrates potential for application in Certification by Analysis, emphasizing the effectiveness of multibody models in enhancing aircraft seat crashworthiness, contributing to safer and lighter designs.

Abstract ID: 319

Efficient Unbalance Variation in Condensed FE Models

Bauer, Klaus-Dieter[1,2]; Offner, Günter[3]
[1]Johann Radon Institute for Computational and Applied Mathematics, Linz, Austria; [2]MathConsult GmbH, Linz, Austria; [3]AVL List GmbH, Graz, Austria

Parameter studies across unbalance variations of condensed FE models are unattractive with previously existing tools, where any variation of the FE model would require a manual reconfiguration in modeling tool, and a computationally expensive condensation of the modified FE model. Within a floating-frame-of-reference formulation, we present an approach that allows instead to add unbalance masses to the already condensed FE model, making the computational cost of the variation nearly negligible and reducing the modification from a manual modeling process to the configuration of a simulation parameter. We demonstrate the use of the formalism by implementing the unbalance modification in an existing multibody simulation code.

Abstract ID: 320

Investigation of Model Fidelity and Parameters for Ride Quality Vehicle Models

Jensen, Christian Futtrup; Hansen, Erik Dyreborg; Sirangelo, Dario; Balling, Ole
Aarhus University, Denmark

This study evaluates vehicle model fidelity for ride quality simulations, focusing on off-road vehicles like the FED-Alpha and Polaris Ranger. Using high-fidelity models (MSC Adams, Project Chrono) and low-fidelity alternatives (MATLAB-based MDOF models), the research investigates the trade-offs between accuracy and computational efficiency. Results reveal that a 7-DOF low-fidelity model achieves accuracy within 10% of high-fidelity benchmarks while reducing computation time by 30-fold. Key vehicle parameters—mass, damping, and wheelbase—significantly influence ride quality metrics, including ISO2631 RMS accelerations and absorbed power. Low-fidelity models excel in preliminary design and sensitivity analyses, but high-fidelity models remain indispensable for extreme conditions and detailed validation. This work aligns with NATO's STANREC standards and proposes a tiered approach to simulation, balancing precision and efficiency.

Abstract ID: 321

Modelling Dynamic Leg Movements Using Finite Element Analysis of the Achilles Tendon Deformation

Nemov, Alexander; Obrezkov, Leonid; Matikainen, Marko
LUT University, Finland

Recent cadaver and animal studies revealed complicated structure of the Achilles tendon consisting of three twisted subtendons. However, current knowledge lacks understanding of how these subtendons work during various leg movements, and in particular, what is the distribution of stresses in subtendons. Multibody models adopted in biomechanics are largely based on Hill-type models of muscle-tendon units, and while this approach can describe overall force-displacement relationship, it does not provide any insight into the distribution of stresses and strains within a tendon.

We address this challenge by proposing a computational approach to modelling the Achilles tendon deformations during movements using a multibody dynamic model of the leg and a finite element model of the Achilles tendon. The connection between the simulations performed with these models is implemented by a modified Hill-type model of the muscle-tendon unit where the response of the finite element model is requested at each time step of the dynamic simulation. Using the developed models, we study the behavior of the Achilles tendon during dynamic foot movements.

Abstract ID: 322

Reduced Model for Efficient Representation of Flexible Tire-Terrain Interaction

Maleki, Mahdi; Kovecses, Jozsef
Department of Mechanical Engineering and Centre for Intelligent Machines, McGill University, Canada

Tire dynamics play a crucial role in vehicle behaviour, and tire-terrain interaction at the contact patch is influenced by tire structure. Accurately capturing tire flexibility often requires complex models like lumped parameter or finite element models, but these come with high computational costs and rising challenges for real-time simulation. In this study, we developed a simplified yet accurate model for flexible tire-terrain interaction to strike a balance between computational efficiency and accuracy within vehicle simulations. Our approach is to integrate the effective stiffness of a flexible tire into a rigid wheel model. We use a rigid wheel model to represent the tire motion. Then, we calculate the effective stiffness of a flexible tire and use that value to adjust the contact parameters to account for the effect of tire deformation. By doing so, we aimed to capture the essential dynamics of tire flexibility while minimizing computational costs. This combination allows us to maintain computational efficiency while ensuring accurate modelling of tire dynamics and interactions.

Abstract ID: 323

Automated Customization of Human Multibody Models for Optical Motion Capture and Analysis

Beron, Santiago; Lugrís, Urbano; Michaud, Florian; Cuadrado, Javier
University of A Coruña, Spain

When using motion capture to analyze human motion, the results are largely dependent on the quality of the underlying rigid-body model. Both its geometry and inertia parameters need to be properly estimated in order to obtain accurate results. Although methods exist to experimentally measure these parameters, they are mostly based on medical imaging, so they are complex and require equipment that is not commonly available. For this reason, the most frequent approach is to resort to scaling and/or optimization techniques, both for estimating the geometry and the inertia parameters. In clinical settings, it is important that the model calibration prior to motion capture is as simple and short as possible, so that it is easy and straightforward to perform by clinical staff, and also does not subject the patient to a long and tedious measurement and calibration process. Since the existing estimation methods do not fulfill these requirements, this work aims to provide a fast and fully automated procedure to obtain an optimal model, by using only a few seconds of motion capture data, and without the need to perform any further measurements on the patient.

Abstract ID: 324

Dynamic Analysis of Flexible Forestry Crane Booms with Different Material Assessment

Gupta, Tirtha Sen; Walica, Dominik; Khadim, Qasim; Kurvinen, Emil
University of Oulu, Finland

Lightweight structures are becoming increasingly prevalent due to their environmental and structural advantages. In this study, the dynamic analysis of forestry crane lift booms is conducted to assess lightweight material alternatives to traditional structural steel. Utilizing hydraulic actuation, flexible multibody dynamic simulations, and the nodal-based floating frame of reference formulation (FFRF), the study compares the structural performance of variants made of high-resistance steel S890 and aluminum alloy Al 6063 T6 to that of structural steel S355. The findings demonstrate that all material variations can sustain the dynamic loads that were evaluated, with aluminum showing the most noticeable vibrations because of its reduced rigidity. Under dynamic loading, the high-resistance steel S890 works admirably since it has the same density as S355 but is stronger. According to preliminary results, structural optimization may be able to reduce the weight of forestry crane components without sacrificing dynamic performance. In order to optimize the advantages of lightweight designs in sustainable forestry gear, future research will concentrate on assessing energy usage and optimizing hydraulic circuits.

Abstract ID: 326

Advancing Rail Track Irregularity Classification with Machine Learning and Multibody Simulation Techniques

Torres, João; Pagaimo, João; Magalhães, Hugo; Vieira, Susana
IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Portugal

Railway track geometry maintenance is crucial for the comfort, safety, and efficiency of railway operations. However, traditional inspection systems rely on costly specialized vehicles, limiting inspection frequency, and resulting in large intervals between maintenance activities. To address these limitations, a vehicle's dynamic response-based methodology is developed to classify rail track irregularities based on a multibody (MB) model of the EM120 inspection vehicle and machine learning (ML) techniques. MB formulation is used to simulate realistic operating conditions of railway vehicles, helping to analyse interactions between the vehicle behaviour and track irregularities. The dataset to develop the ML models is built using data from 1014 km of track with known track irregularities, classified according to its condition, and bogie frame motion, including accelerations and angular velocities. Different Support Vector Machine (SVM) models are then evaluated with performance metrics. The results highlight the strong correlation between track irregularities and bogie frame dynamics, enabling accurate classification of track sections. The Gaussian SVM achieved the highest performance metrics, underscoring its reliability and robustness. This research demonstrates the feasibility of continuous track monitoring using a sensor module mounted on the bogie frame to measure its dynamic behaviour, enabling the development of scalable, data-driven maintenance strategies.

Abstract ID: 327

THREAD - A European Graduate School on Modelling and Simulation of Highly Flexible Structures

Arnold, Martin[1]; Brüls, Olivier[2]; Celledoni, Elena[3]; Gerstmayr, Johannes[4]; Jelenić, Gordan[5]; Leyendecker, Sigrid[6]; Linn, Joachim[7]
[1]Martin Luther University Halle-Wittenberg, Germany; [2]University of Liège, Belgium; [3]NTNU Trondheim, Norway; [4]University of Innsbruck, Austria; [5]University of Rijeka, Croatia; [6]Friedrich-Alexander University Erlangen-Nuremberg, Germany; [7]Fraunhofer ITWM, Germany

From October 2019 to March 2024, the Joint Training on Numerical Modelling of Highly Flexible Structures for Industrial Applications [THREAD] was funded as a Marie Skłodowska-Curie Innovative Training Network in the research and innovation programme Horizon 2020 of the European Union. Twenty-six academic and industrial partners from eleven European countries studied the mechanical modelling, mathematical formulations and numerical methods for highly flexible slender structures like yarns, cables or ropes. The research followed a holistic approach starting from detailed 3D modelling and experimental work to build validated 1D nonlinear rod models, which are finally brought to efficient system-level simulation with novel geometric numerical integration methods. In the present paper, we summarise essential results of the THREAD graduate school and show that such large-scale projects may strengthen the scientific communities substantially.

Abstract ID: 329

Application of the Extended Kalman Filter for Constraint Enforcement in the Forward Dynamics of Multibody Systems

Richiedei, Dario[1]; Tamellin, Iacopo[2]; Trevisani, Alberto[1]
[1]University of Padova, Italy; [2]University of Verona, Italy

The simulation of the forward dynamics of multibody systems enforces the acceleration constraint while position and velocity constraints are violated due to numerical integrations errors, i.e., round-off and discretization or truncation errors. This is a critical issue, indeed simulation experiences instabilities and the results quality is deteriorated. Several approaches have been developed over the decades to cope with this issue. The novel idea proposed in this paper is to exploit the Extended Kalman Filter (EKF) to control the constraint violation. The forward dynamics is interpreted as a state estimation performed through the prediction-correction scheme of the EKF. The prediction at each time-step is the integration of the equations of motion, while the correction is the constraint enforcement. The EKF is adopted since it provides an approximation of the optimal estimator. Then, the duality between estimation and control enables to use the EKF as a controller to enforce position and velocity constraints, i.e., to track the zero value. The proposed method is novel and its application to a benchmark taken from the literature highlights the effectiveness of the proposed method which is compared with the well-established Baumgarte constraint stabilization method.

Abstract ID: 330

Deep-Koopman-Ehnanced Kalman Filter for Cable-Driven Parallel Robots

Boscariol, Paolo; Dona', Domenico; Richiedei, Dario; Trevisani, Alberto
Department of Management and Engineering (DTG), University of Padua, Italy

This work presents a novel approach for state estimation in Cable-Driven Parallel Robots (CDPRs) by integrating Koopman operator theory into the Kalman Filter framework, in a proposed Koopman Extended Kalman Filter (KeKF). CDPRs, known for their large workspace and mechanical simplicity, pose significant challenges in state estimation due to their nonlinear dynamics and cable-induced uncertainties. The KeKF leverages the Koopman operator to linearize the nonlinear dynamics globally, thereby enhancing the accuracy of state estimation compared to traditional Extended Kalman Filters. The effectiveness of the proposed method is demonstrated through numerical experiments, highlighting its superior performance in estimating the state of a suspended CDPR with a point mass end-effector. This study underscores the potential of KeKF in improving state estimation in complex robotic systems.

Abstract ID: 333

Parameter Optimization of a MWSM Shock-Test Multibody Model Through SRS Analysis

Lopez Varela, Álvaro[1,2]; Rodriguez González, Antonio[1,2]; Meijido López, Vicente[4]; Bello Corbeira, Constantino[4]; Dopico Mayobre, Juan[4]; Fariñas Alvariño, Pablo[2,3]; Cuadrado Aranda, Javier[1]; Dopico Dopico, Daniel[1]

[1]Laboratorio de Ingeniería Mecánica, Universidade da Coruña, Spain; [2]Centro Mixto de Investigación Navantia-UDC, Universidade da Coruña; [3]Grupo de Investigación en Sistemas Térmicos y Transferencia de Calor, Universidade da Coruña; [4]Navantia

The Medium Weight Shock Machine (MWSM) is a machine used to test equipment installed on warship vessels. These tests are required to ensure that the equipment is able to withstand an eventual underwater explosion (UNDEX) without contact with the hull. The simulation of a shock test in a MWSM requires a considerable number of bodies, forces and constraints whose properties are difficult to adjust from experimental data or field measurements. Therefore, a parameter optimization is proposed using contact force coefficients, structural damping coefficients, or elastic properties of the flexible bodies (among others) as the set of system parameters. A measurement of the convergence of the Shock Response Spectrums (SRS) between the simulation and the experimental results obtained from shock tests with dummy loads in a real MWSM is considered as the objective function. The parameter optimization is approached with a combination of global and gradient-based optimization algorithms, providing a significant improvement in terms of convergence.

Abstract ID: 334

Kinematics of Single-Degree-of-Freedom Closed-Loop Systems with C2 Hermite Spline Interpolation

Capette, Nicolas[1]; Houdek, Vaclav[2]; Verlinden, Olivier[1]; Olivier, Bryan[1]
[1]University of Mons, Belgium; [2]University of West Bohemia, Czech Republic

The dynamics of multibody systems comprising kinematic loops, approaches based e.g. on Cartesian or relative coordinates, will consider some joints in the form of constraint equations. The latter are combined with the equations of motion through Lagrange multipliers, leading to a set of differential algebraic equations where kinematics and dynamics are solved simultaneously. On the other hand, the approach based on minimal coordinates consist of solving firstly the kinematics so as to express the now ordinary equations of motion in terms of independent configuration parameters. In order to avoid to solve the same constraint equations for very similar configurations (e.g. when a vehicle suspension bounces up and down), this paper proposes to construct a look-up table gathering the kinematics for a set of configurations and to interpolate the motion from the table during the dynamic simulation. The interpolation addressed in this paper has specific requirements as the motion must be reproduced accurately with at least C1 continuity and ideally C2 continuity to avoid kinetic energy and acceleration jumps respectively. The C2 interpolation procedure is tested on 1 DOF meschanism such a 3D slider mechanism and a double wishbone suspension in the future.

Abstract ID: 335

Impact of Worn Wheel and Rail Profiles on Optimal Steering Parameters of Actively Steered Wheelsets via Sensitivity Analysis

Lindbichler, Lukas; Klanner, Michael; Melito, Gian Marco; Ellermann, Katrin
Institute of Mechanics, Graz University of Technology, Austria

Rail vehicle guidance involves a trade-off between high-speed stability and curving performance. High longitudinal stiffness in the wheelset suspension enhances stability but harms curving performance, leading to wear and increased operational costs. Active yaw relaxation systems, such as radial and optimized steering, offer significant improvements by reducing wheel and rail wear. This study investigates the impact of worn wheel and rail profiles on steering parameters. A multibody vehicle model simulates wheel-rail interactions, integrating wear predictions through iterative profile updates. Sensitivity analyses consider track geometry, wear conditions, and varying states of wheel reprofiling. Results highlight the substantial influence of worn profiles on the steering parameter, with the potential to extend wheel lifespan by dynamically adjusting it based on wear conditions. Optimized steering reduces rolling contact fatigue and wear but is sensitive to rail wear patterns. Adapting steering strategies to account for worn profiles improves vehicle dynamics and operational efficiency, enhancing the durability of both wheels and rails while reducing maintenance costs.

Abstract ID: 336

Discrete Adjoint Sensitivities for Optimal Control of Musculoskeletal Multibody Models

Sonneville, Valentin; Moreno, Benjamin; Brüls, Olivier
Universtié de Liège, Belgium

This work addresses the challenges in designing wearable devices such as prostheses and exoskeletons by integrating advanced multibody dynamics and musculoskeletal modeling. Existing tools like OpenSim excel in musculoskeletal analysis but lack robust multibody dynamics, while physics engines like MuJoCo prioritize visual rendering over precision, limiting their application in assistive device optimization. The authors present a novel framework based on Odin, an open-source software that combines state-of-the-art multibody dynamics with musculoskeletal modeling. Odin employs a finite-element approach to handle complex system topologies, kinematic loops, and non-smooth dynamics efficiently. It integrates the Hill-type muscle model by De Groote and Fregly, with OpenSim serving as a pre- and post-processor. This framework facilitates the optimal control of musculoskeletal systems and wearable devices, minimizing metabolic cost and maximizing performance metrics. A discrete adjoint optimization method is implemented to reduce computational costs associated with solving large-scale optimization problems. By introducing adjoint variables, state derivative computations are avoided, enhancing efficiency. The framework is validated through test cases, including an upper-body exoskeleton and a leg prosthesis, demonstrating its potential for designing and optimizing personalized assistive devices while paving the way for digital twins and customized solutions.

Abstract ID: 337

Analysis of a Bennett Linkage Using the Geometric Algebra Approach

Alwis Weerasinghe, Sachintha[1]; Dileri, Eirini[1]; Ebel, Henrik[1]; Poštulka, Tomáš[2]; Huňady, Róbert[2]; Mikkola, Aki[1]; Bauchau, Olivier[3]; Orzechowski, Grzegorz[1]
[1]LUT University, Finland; [2]VSB – Technical University of Ostrava, Czech Republic; [3]University of Maryland, United States

The Bennett mechanism is an overconstrained four-bar mechanism with strict geometric constraints. This study plans to analyse its kinematics and dynamics using Simscape and Geometric Algebra (GA), a framework offering singularity free representations of rigid-body motion. Simscape simulations of the CAD model reveals challenges with numerical accuracy due to overconstraints, addressed by substituting a revolute joint with a bushing joint. Torque characteristics are analysed in Simscape under constant angular velocity, highlighting a consistent torque spike. Concurrently, GA approach will be implemented offering a unified approach to the system's behaviour. Results from both methods will be compared to validate the accuracy of the GA approach and its potential applications in multibody dynamics. Furthermore this analysis is expected to reveal insights into potential real-world applications of the Bennet mechanism. Future work includes sensitivity studies and refining joint alignment in simulations for improved accuracy.

Abstract ID: 338

Control Ring and Air Drag Effects on Yarn Balloon Dynamics in Ring Spinning: A Spring-Mass Modeling Approach

Perez-Delgado, Yves Jesus[1]; Beitelschmidt, Michael[1]; Hossain, Mahmud[2]; Abdkader, Anwar[2]; Cherif, Chokri[2]; Baloochi, Mostafa[3]; Hühne, Ruben[3]
[1]Institute of Solid Mechanics (IFKM), TUD Dresden University of Technology, Dresden, Germany; [2]Institute of Textile Machinery and High Performance Material Technology (ITM), TUD Dresden University of Technology, Dresden, Germany; [3]Leibniz Institute for Solid State and Materials Research Dresden, Dresden, Germany

The ring-spinning is one of the most used processes to produce yarn but faces limitations due to friction in the ring/traveler system; innovations such as superconducting magnetic bearings have significantly increased spindle speeds to 50,000 rpm, leading to the necessity of continuing the yarn dynamics research. Traditional models for yarn balloon dynamics involve complex formulations, but a spring-mass chain approach simplifies the analysis while maintaining essential behaviors. In this contribution, different effects were added to the spring-mass approach, such as air drag, contact with the control ring, and the flow of the fibers through the yarn. The addition of the drag force leads to a three-dimensional yarn balloon in a steady state. The contact between the control ring and the yarn balloon is modeled as a rigid body contact using a spring. The final steady-state solution worked as a point of equilibrium for linearizing the system and analyzing the natural oscillations. Additionally, the influence of the fibers flowing through the yarn path was tested using the impulse-momentum equation, showing that the flowing material effect can be neglected.

Abstract ID: 339

A Simplified Implementation of Recursive Dynamics for Flexible Multibody Systems

Yu, Xinxin[1]; Mikkola, Aki[2]
[1]Tampere University; [2]LUT University

Semi-recursive dynamic algorithms are widely used in multibody applications due to their numerical efficiency, making them well-suited for computationally critical tasks such as real-time simulation. However, relatively few publications address flexible multibody systems using this approach. The challenge lies in accurately forming the velocity transformation matrix, which incorporates the effects of joint type and body deformation to describe the relative motion between connected bodies in the open loop. This paper provides a new definition of the joint coordinate system, leading to a simplified derivation of this velocity transformation matrix for flexible bodies. Multibody modeling analysts familiar with global formulations can easily extend their knowledge to accommodate this new approach.

Abstract ID: 340

Optimal Design of a Flushing Gate with Variable Counterweight for Self-Actuating Desanding Systems

Gufler, Veit[1]; Wehrle, Erich[2]; Gufler, Alfred[3]
[1]Free University of Bozen-Bolzano, Italy; [2]Autonomous research; [3]Gulfer Metall KG, Italy

In this work, optimization-based integrated design of structural, kinematic and loading parameters of mechanical systems is introduced with flexible multibody dynamics. The introduced methodology is shown on the example of a self-actuating flushing gate mechanism for desanding systems of hydroelectric power plants. The pressure difference between a sole membrane and a wall membrane is monitored and the exceeding of a threshold value due to deposited sediments triggers the filling of the counterweight tank, which in turn opens the segment gate and initiates the flushing of the basin. The conceptual design of this system presents several challenges, which include integrated dynamic and structural mechanical analysis requiring the consideration of various types of design variables. The design variables include those associated with the kinematic design to guarantee a proper function of the mechanism. Lightweight design is applied to reduce material consumption and costs while ensuring compliance with the load limits of the components. Additionally, control design is considered for allowable opening and closing times of the gate. Flexible multibody dynamics allows to simulate all these considerations in one model and integrated design is achieved with numerical design optimization. Efficient optimization is enabled by the use of gradient-based algorithms and analytical sensitivity analysis.

Abstract ID: 341

Thermodynamic Modelling of Degraded Adhesion in Railway Wheel-Rail Contact

Shi, Zhiyong[1]; Meli, Enrico[1]; Sun, Yu[2]; Rindi, Andrea[1]
[1]University of Florence, Italy; [2]Nanjing Tech University, China

A novel degraded adhesion model for railway applications is developed to analyze thermal effects and adhesion recovery during wheel-rail interactions. By incorporating large sliding, energy dissipation, and heat transfer phenomena, the model provides a comprehensive thermodynamic framework. The total dissipated energy is primarily attributed to heat flux, validated through laboratory measurements and simulations. Key parameters in the heat transfer equations linked temperature evolution at the contact point to mechanical and thermal processes. The results demonstrate the accuracy of the model in predicting adhesion behavior and energy dissipation under degraded conditions, offering insights for improving railway system safety and performance.

Abstract ID: 342

Variational Integrators for a Lagrangian Formulation of Control Affine Systems with Quadratic Cost

Konopik, Michael[1]; Leyendecker, Sigrid[1]; Maslovskaya, Sofya[2]; Ober-Blöbaum, Sina[2]; Sato Martín de Almagro, Rodrigo T.[1]
[1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; [2]Universität Paderborn

For a new Lagrangian framework of solving optimal control problems with quadratic running cost and affine controlled second-order dynamical constraints variational integrators are derived using the theory of discrete mechanics. These naturally lead to symplectic methods on the level of the optimal control space and discretize the running cost and dynamic constraint in a consistent way.

Abstract ID: 343

Chrono::DEM: A GPU-Accelerated Multiphysics Solver for Granular Dynamics and Heat Transfer Application

Bakke, Luning; Zhang, Ruochun; Negrut, Dan
University of Wisconsin - Madison, United States of America

Chrono::DEM is an open-source, GPU-accelerated Discrete Element Method (DEM) solver designed for multiphysics applications such as granular dynamics, terramechanics, and heat transfer. Its architecture decouples collision detection from dynamic computations, optimizing computational efficiency for large-scale simulations. The solver enables user-defined contact laws and heat transfer models through customizable CUDA 's Just-In-Time (JIT) compiler. With a heat exchanger application, we showcase its ability to model heat transfer in granular systems with experimental validation against temperature results. Chrono::DEM significantly outperforms traditional CPU-based solvers in computation speed, achieving faster results with higher particle counts. These features establish Chrono::DEM as a versatile and high-fidelity tool for addressing multiphysics and multiscale challenges in granular systems.

Abstract ID: 344

Reduced-Order Interface Elements for Extremity Solutions in Piezoelectric Beams with Arbitrary Cross-Section

Seinhorst, Bram; Nijenhuis, Marijn; Hakvoort, Wouter
University of Twente, The Netherlands

Prismatic structures can be accurately modeled with beam elements if they are slender. Near the interfaces at the ends, classical beam solutions lose accuracy (St. Venant's principle), in particular for shorter beams. In this work, a model-order reduction technique is presented for improved accuracy in the static behavior of geometrically nonlinear beams near the interfaces at their ends. The beams have arbitrary cross-sectional geometry and material, including piezoelectric effects. The reduction technique is based on a decomposition into nonlinear nondecaying central beam behavior and linear decaying extremity behavior. The extremity effects are condensed into an equivalent interface stiffness. The corresponding interface element has been implemented for use with geometrically nonlinear beam elements in flexible multibody simulations. The accuracy of the approach has

been validated against COMSOL. The validation cases show significant accuracy improvements in the stiffness, reconstructed stress field and the voltage-deflection coupling.

Abstract ID: 345

Dynamic Simulation of Constrained Multibody Systems with Electromechanical Actuators Using a Monolithic Approach

García-Agúndez Blanco, Alfonso[1]; Mikkola, Aki[1]; García-Vallejo, Daniel[2]; Serban, Radu[1,3]; Mattsson, Aleksi[4]; Peltoniemi, Pasi[4]
[1]LUT University, Finland; [2]Universidad de Sevilla, Spain; [3]University of Wisconsin-Madison, United States of America; [4]LUT University, Finland

Electromechanical actuators (EMAs) are gaining significant interest across numerous industries, such as aerospace engineering or heavy machinery, by offering precise motion control, high efficiency, and straightforward integration with electronic systems. In heavy machinery applications, EMAs are capable of delivering the necessary torque and power while remaining robust in harsh operating conditions, providing a cleaner solution compared to conventional hydraulic systems. In this work, the dynamic simulation of constrained multibody systems actuated with EMAs is illustrated by means of a monolithic approach. The coupling between the mechanical subsystem dynamics and the electric drive is considered. The electric actuator is modelled by using a d-q model of a permanent-magnet synchronous motor (PMSM). As a case study, the dynamic simulation of a four-bar mechanism with an EMA is presented, demonstrating an excellent computational efficiency.

Abstract ID: 348

Stability Control of Two-Wheeled Trailers with Different Contact Force Models

Horvath, Hanna Zsofia[1]; Takacs, Denes[1,2]; Antali, Mate[3]
[1]Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Department of Applied Mechanics, Hungary; [2]HUN-REN–BME Dynamics of Machines Research Group, Hungary; [3]Szechenyi Istvan University, Department of Applied Mechanics, Hungary

Trailers are often involved in road accidents since many drivers do not choose the towing speed and/or the payload position appropriately. The snaking motion of towed two-wheeled trailers is investigated in this study using a spatial, 4-DoF model. Namely, the yaw, pitch, and roll motions are all taken into account. The non-smooth effects of the wheel suspension characteristics and the detachment of the wheels from the ground are considered. A simple linear state feedback controller is designed to reduce unwanted vibrations. Contact force models with different levels of complexity are considered. The 1D creep models include pure lateral creep. During acceleration and braking, longitudinal creep can be significant. Therefore, a 2D creep model is also created where the effects in the longitudinal and lateral directions are coupled. The results of the numerical bifurcation analysis show that the globally stable region can be extended with the applied linear state feedback controller.

Abstract ID: 349

Control Design for Generating Motorcycle Dynamic Data with Realistic Rider Behavior

Schön, Alexander[1,2]; Joerg, Hannah[1]
[1]University of Applied Sciences Landshut, Germany; [2]x-log Elektronik GmbH, Germany

This work presents a control model structure of a virtual rider, which is optimized for the representation of cornering on country roads with individual rider behavior including riding errors or riding anomalies. Background is the development of a method for simulating the characteristic rider behavior of a motorcyclist in a multi-body simulation environment, which is used for scenario-based IMU data generation. The simulation model includes an environmental model, a motorcycle model with the IMU sensor and the virtual rider. The virtual rider comprises a trajectory planning algorithm, a nonlinear model predictive control (MPC), which uses simplified nonlinear description of the motorcycle model for optimization, and an execution errors element. The execution errors element can manipulate the nonlinear MPC output for a more realistic execution. The control strategy has a feedback loop to update the trajectory planning algorithm with information from the motorcycle model. The aim is to generate large datasets of realistic motorcycle dynamic data based on different rider behaviors to train an artificial intelligence method, which is used to identify the rider's individual rider behavior during a real ride.

Abstract ID: 351

A Kinematic Description for Modal-Based Wheels

Bozorgmehri, Babak[1]; Orzechowski, Grzegorz[1]; Matikainen, Marko K.[1]; Serban, Radu[1,2]; Mikkola, Aki[1]
[1]LUT University, Finland; [2]University of Wisconsin-Madison

This paper presents a novel modal-based kinematic description within the framework of flexible multibody dynamics. By employing a non-rotating reference frame, the proposed approach addresses the limitations of classical methods such as the Floating Frame of Reference Formulation (FFRF) in simulating tire-road interactions. Notably, it avoids introducing a new set of shape functions for each rotational pitch, significantly reducing computational complexity. The first and second bending modes, as well as their combination, are effectively captured with respect to an intermediate non-rotating body frame. This efficient approach maintains accuracy and potentially is well suited for real-time applications in vehicle dynamics.

Abstract ID: 352

On the Simulation and Analysis of Contact Using an MSD-FEM Co-Simulation Methodology

Melo, Francisco Guedes; Gonçalves, Sérgio Barroso; Areias, Pedro; Silva, Miguel Tavares
IDMEC, Instituto Superior Técnico, Portugal

In multibody systems dynamics (MSD) the use of analytical methods for detecting contact using a collection of points or simple geometric shapes offers significant advantages in terms of computational efficiency. However, these models often oversimplify the contact surfaces, limiting the accuracy of the results. An alternative approach involves using more complex geometries that better represent the shape of the bodies in contact. However, the methodologies needed to detect and process contact are typically more expensive from a computational point of view, although having the potential to yield additional information. Considering that a finite element method (FEM) approach is used to evaluate contact mechanics, additional information such as the pressure contact map, or the internal stresses and deformations of the bodies in contact can also be obtained. This information can be extremely relevant for many engineering fields, in which the design of medical devices is included. Over the past two decades, numerous works have been published using a co-simulation approach between MSD and FEM. This work explores the applicability of employing a unidirectional and bidirectional MSD-FEM co-simulation approach to conduct inverse and forward dynamic analyses of two multibody systems characterized by the presence of contact.

Abstract ID: 353

A Double Shooting Method for Two-Point Boundary Value Problems in Multibody Dynamics

Eichmeir, Philipp[1,2]; Steiner, Wolfgang[1,2]
[1]Vienna University of Technology; [2]University of Applied Sciences Upper Austria

The solution of two-point boundary value problems (TPBVPs) in multibody system dynamics is a tough challenge. In this article, a double shooting method (DSM) tailored for two-point boundary value problems is presented. The method builds upon the classical single shooting method while incorporating optimization strategies to overcome numerical instability and sensitivity to initial guesses. The conventional shooting method is associated with some numerical problems: The numerical gradient computation for updating initial values causes problems in many cases, since the disturbance parameter for determining the numerical derivative must be selected appropriately in order to achieve sufficient accuracy, and integrating the initial value problem can be numerically challenging, especially when the interval is large and the differential equations have unstable modes. The DSM is designed to address these challenges. Therefore, the method incorporates a discrete costate variable approach to address the numerical gradient computation, which is often the Achilles' heel of classical shooting methods. Finally, the method is formulated using a discrete implicit integration scheme to determine the optimal control of a robot multibody model.

Abstract ID: 354

Energy Efficient Concept of Dual Double Pendulum System with Passive Spring Elements

Krivošej, Jan; Švadlena, Jakub; Šika, Zbyněk
CTU in Prague, Czech Republic

The paper deals with a system with four degrees of freedom, which includes additional auxiliary passive elements. The configuration is shaped to form a dual double pendulum, where actuators are present in each rotary joint and the connection is provided by springs. The aim of the assembly is to target partial demonstrator of the exoskeleton connection with the upper limb in the sagittal plane for rehabilitation movements, using the properties of series and parallel elastic actuators and advanced control algorithms with implementation of the eignemotion principle for a system with multiple degrees of freedom.

Abstract ID: 355

Compensatory Foot Placement Estimation for Impulsive Torso Perturbation

Goswami, Bhavya Giri; Arami, Arash; McPhee, John
University of Waterloo, Canada

Compensatory stepping is a reactive balancing strategy used to counteract high-magnitude unexpected perturbations by adjusting the functional base of support polygon, by taking a step in the direction of the perturbed center of mass velocity, to bring it to rest. It has been shown that the stepping parameters (like step time and length) depend on the magnitude of perturbation, but estimating the foot placement position also depends on the perturbation type. A high-fidelity compensatory stepping model with stepping predictor can help us develop better controllers for exoskeletons, prosthetics, and humanoid robots, to get human-like behavior. In this work we propose a double inverted pendulum based Compensatory Foot Placement Estimator (CFPE) model, specifically for impulsive torso perturbation, taking into account significant factors such as knee bending and swing leg dynamics. Without making any pre-contact walking-like assumptions, the Genetic Algorithm was utilized to determine the optimum step length and duration that minimizes the cost on margin of instability, recovery effort, step time, step length, and joint torque. Impulsive torso perturbation experiments were also performed on healthy adults with various sensor modules to compare our model results. Preliminary results show that the stepping parameters from our model aligns well with the experimental data.

Abstract ID: 359

Comparative Multibody Study of Spring Isolation Systems for Vibrating Screens

Galli, Davide[1]; Nezzi, Chiara[1]; Gufler, Veit[1]; Vidoni, Renato[2]
[1]Free Univeristy of Bozen/Bolzano, Italy; [2]Università degli Studi di Udine, Italy

Vibrating screens are vital in industries requiring particle size separation, such as mining, pharmaceuticals, food processing, and recycling. These machines use vibrating screens or meshes to separate materials efficiently. Their dynamics depend on interactions between components like springs, mo-

tors, and meshes, which influence vibration amplitude, frequency, and motion path. The design of isolating systems is particularly critical for performance and accuracy. Traditional systems often use steel coil springs, as extensively documented in the literature. However, these systems are prone to resonance issues, limiting efficiency. This study investigates an innovative solution, replacing coil springs with Neidhart springs, which are systems of swinging elements connected by metal-elastomer torsion springs. Multibody models of both traditional and modern vibrating screens are developed, and their harmonic responses are simulated in the MSC ADAMS environment. Results show that screens with Neidhart springs have a shallower frequency response and reduced amplitudes, indicating lower vulnerability to excitation over a wide frequency range. This modern approach effectively mitigates resonance problems.

Abstract ID: 361

Nonlinear Dynamics of Imperfect Mechanical Systems with Friction

Hajžman, Michal; Hrabačka, Martin; Bulín, Radek; Byrtus, Miroslav; Dyk, Štěpán
University of West Bohemia, Czech Republic

This work focuses on mechatronic systems and devices where motion and performance are influenced by both friction (passive effects) and joint clearances. These two characteristics oppose each other, making it essential to understand their combined impact on system positioning and dynamics for effective design. Our goal is to analyze how joint clearances and friction interact to influence the dynamic behavior of selected multibody systems, ultimately leading to the development of active compensation methods. To create computational models of the studied mechanical systems, we use a methodology based on the Cartesian coordinates of individual bodies and Lagrange equations to formulate the equations of motion, combined with a force-based representation of imperfect joints with clearance and friction. The results indicate that the dynamic behavior qualitatively changes depending on the combination of joint clearances and friction levels. To support the theoretical findings, a series of experimental measurements was proposed on the reconfigurable complex mechanism.

Abstract ID: 362

Modeling Musculoskeletal Systems Using a Multibody Formulation with Fully Cartesian Coordinates and a Generic Rigid Body

B. Gonçalves, Sérgio[1]; Flores, Paulo[2]; Silva, Miguel Tavares da[1]
[1]IDMEC, Insituto Superior Técnico, Universidade de Lisboa, Portugal; [2]CMEMS-UMinho, Departamento de Engenharia Mecânica

The present study focuses on applying the spatial FCC-GRB formulation to the analysis and simulation of biomechanical systems, emphasizing its strengths and limitations relative to other global formulations. It provides an overview of fundamental principles for modeling biomechanical systems, including musculotendon units and contact problems. Additionally, the study explores integrating mixed-coordinate approaches for inverse kinematic analysis using experimental data from conventional optoelectronic marker-based systems. To assess the performance of the FCC-GRB formulation, it was applied in the analysis of various biomechanical models, ranging from single-joint systems to comprehensive full-body models. Overall, the FCC-GRB formulation has proven to be an efficient and straightforward approach for modeling and analyzing biomechanical systems. Its design supports the seamless integration of soft tissue dynamics and contact problems, which are essential for addressing classical biomechanical challenges. Furthermore, its compatibility with a

mixed-coordinates framework enables straightforward data processing without the need to compute joint drivers. These features make the FCC-GRB formulation highly beneficial for the biomechanics research community. It simplifies the development and implementation of new biomechanical models, reducing the need for extensive expertise in computational mechanics.

Abstract ID: 363

A Non-Smooth Approach for Multiphysics Modeling of Tibiofemoral Joint Contact Forces Under Impact Loading

Morshed, Abu Hena MD Maruf[1]; Chatterjee, Abhishek[2]; Ricard, Mark[1]; Prisby, Rhonda[1]; Bowling, Alan[1]

[1]University of Texas at Arlington, United States of America; [2]University of Twente, The Netherlands

The act of walking and running is not as mechanically benign as might be commonly assumed. When a heel strikes the ground, the body undergoes high-frequency impulse loads, meaning it experiences large and abrupt contact forces distributed over the tibiofemoral joint surfaces. The study of these contact forces could reveal new insights related to the diagnosis and prognosis of osteoarthritis. In-vivo measurement of joint forces is impossible, making computational models essential for their study. To do this, the model must include rigid bodies such as bones, flexible bodies, and fluids such as synovial fluid, making this a multiphysics model. During impact, the interaction between fluid and bone surfaces resembles a rigid body collision due to the rapid, brief nature of the event, causing negligible deformation or positional change. This behavior motivates the application of rigid body impact principles within a multiphysics model of the tibiofemoral joint. Instead of simulating a complex anatomical system, the approach is tested on a two-block model with ligaments and synovial fluid to assess its behavior. The results closely matched the expected response of a flexible structure, validating the effectiveness and credibility of the proposed rigid body impact approach.

Abstract ID: 364

A New Hip Cable-Driven Wearable Assistive Device to Reinforce Human Balance

Muscolo, Giovanni Gerardo[1]; Sancisi, Nicola[2]; Conconi, Michele[2]; Del Felice, Alessandra[3,4]; Chiari, Lorenzo[1]

[1]Department of Electrical, Electronic, and Information Engineering Guglielmo Marconi, Università di Bologna; [2]Department of Industrial Engineering, Università di Bologna; [3]Department of Neuroscience, Section of Neurology, University of Padova; [4]Padova Neuroscience Center, University of Padova

This work presents a multibody human model combining a new hip cable-driven wearable assistive device (WAD) for postural control. The WAD aims at reinforcing human balance in response to an unexpected external perturbation generated by antero-posterior or latero-lateral tilting. The multibody analysis presented in this work fosters the optimization of the design and control architectures for the WAD, reducing the number of actuators, weight of the WAD, and power consumption.

Abstract ID: 366

An Analysis of the Mobility Performance of the Apollo Mission Lunar Roving Vehicle (LRV)

Witt, Bret[1]; Haque, Jamiul[1]; Chen, Patrick[1]; Unjhawala, Huzaifa[1]; Arivoli, Ganesh[1]; Zhang, Harry[1]; Zhou, Zhenhao[1]; Santelia, Matteo[2]; Reato, Federico Maria[3]; Tasora, Alessandro[4]; Bakke, Luning[1]; Serban, Radu[1]; Negrut, Dan[1]
[1]University of Wisconsin-Madison, United States of America; [2]Politecnico di Milano, Italy; [3]Iseo Serrature Spa - Microhard Srl, Italy; [4]University of Parma, Italy

This is an extended abstract of a planned full paper submission that demonstrates a methodology to carry out an analysis of the mobility performance of the Lunar Roving Vehicle (LRV) associated with the Apollo 15, 16, and 17 missions. The approach employed draws on the open source multi-physics simulation engine Chrono and uses public information associated with the design of the LRV. We present a short overview of the LRV CAD model, discuss the Chrono components used to model the vehicle, its terrain, and report early results of a statistical analysis involving 972 trials that concerns a segment of landscape negotiated by the lunar vehicle.

Abstract ID: 367

Hybrid NN-EOM Approach to Accelerate Multi-Body Simulations

Slimak, Tomas; Todorov, Bojidar; Zwölfer, Andreas
Chair of Applied Mechanics, Technical University of Munich, Germany

Since the EOMs for most applications can be analytically determined, this approach intends to use the known relationships, but accelerate their simulation through use of NNs. Lengthy complex EOMs often arise due to the non-linear coupling through constraints and joints. The hybrid approach splits a larger system into multiple sub-systems with simple EOMs. To couple the sub-systems, reaction forces determined through a NN are used. This separation of the task and hybrid solving enables an exact selection of where time is gained and where accuracy is sacrificed. This brings the data-driven simulation technique closer to a point where expert understanding of the physics can be used to minimize time while maximizing accuracy. By splitting the task it also opens the door for parallelization of independent processes.

Abstract ID: 369

Stability Charts of the Continuous Time Model Predictive Controller

Bodor, Bálint
Budapest University of Technology and Economics, Hungary

Researchers are still investigating the control of multibody dynamics systems, especially underactuated systems, due to their complex dynamics. Underactuated systems' possibly unstable internal dynamics may lead to stability issues for traditional controllers, such as the inverse dynamics control approach. This problem can be tackled by employing optimal control approaches, among which the model predictive control approach is a frequent selection. This approach consists of solving linearized optimal control problems recursively. The appropriate selection of the control parameters

is not trivial. This contribution aims to give a tool to control designers with which the time horizon parameters of the receding horizon control can be tuned. This is done by turning the consecutive optimal control problems into a linear difference equation describing the evolution of the states during the controller's operation. Based on the investigation of this difference equation, stability maps are possible to generate enhancing control parameter selection.

Abstract ID: 370

Force and Friction Inference in Worm Locomotion

Munoz, Jose J[1]; Krieg, Michael[2]; Paddle, Aleksandra[2]
[1]Universitat Politècnica de Catalunya, Spain; [2]Institut of Photonic Sciences (ICFO)

Worm locomotion on is determined by appropriate frictional conditions and bending modes. However, it is still unknown the strategies used by organisms and the optimality of the forces exerted remains also unexplored. We here adapt an optimal control problem to deduce the muscle activity in a worm model during its locomotion on an agar substrate. The computed traction field exerted by the substrate is also validated by the force field measured through Traction Force Microscopy techniques, which compute the tractions produced by the worm from the measured deformation of the substrate. Additionally, we also search optimal strategies by minimizing a functional that measures the distance of the organism to a target point, while reducing the total consumed energy. The model is based on a finite element discretization of the viscoelastic continuum description of the body domain, and the solution algorithm is based on a Forward Backward Seep Method, which solves the optimal control equations in a staggered manner iteratively.

Abstract ID: 371

Incorporating Friction in Model-Based Co-Simulation of Multi-Domain Mechanical Systems

Raoofian, Ali; Kovecses, Jozsef
Department of Mechanical Engineering and Centre for Intelligent Machines, McGill University, Montreal, Canada

Co-simulation involves the simultaneous simulation of different interconnected physical systems using distinct simulation tools. In a co-simulation setup, the subsystems are connected to each other through their interfaces. The interface variables are only being exchanged at certain time points known as communication points with the time-interval called macro time step. As the interface variables are also needed during the macro time step, accurate determination of variables between these communication points is essential. In model-based methods, a reduced interface model (RIM) will be developed which acts as a representative for the mechanical system during the macro time step. This study explores the effects of friction in different modelling strategies of mechanical systems. Friction effect will be examined in two different model-based co-simulation approaches, both of which involve creating a reduced interface model (RIM). The RIM is applied to a representative non-smooth case study in which numerical simulation of hydraulic-mechanical subsystems is carried out. It will be shown that the smooth RIM can produce inaccurate results in certain cases, such as when the system experiences changes in contact state. In contrast, the results obtained from non-smooth RIM were found to be consistent with the reference solution.

Abstract ID: 372

Control-Oriented Linearization Method for Multibody Models

Kuslits, Márton
University of Surrey, United Kingdom

Utilization of multibody models in control-related applications is an emerging research topic given that the capabilities of the embedded systems are evolving and a straightforward development is to use more precise models when controlling multibody systems. When designing controllers, a particular problem is to obtain a linearized counterpart of the nonlinear multibody model. There are two main requirements associated with control-oriented models rendering the linearization difficult: 1) typically, the linearization has to be done along a certain trajectory and thus calculations have to be done at every time step requiring an efficient algorithm, 2) the linearized model must be formulated with problem-specific minimal coordinates while multibody models are typically formulated with redundant coordinates. In this paper, I present a new control-oriented linearization method which is based on the convenient redundant coordinate formulations but provides the results according to the desired minimal coordinates. The proposed method combines the implicit derivation of the equations of motion, state augmentation and velocity projections while takes the implicit dependencies into account producing a numerically identical state matrix compared to that if the model was derived and linearized directly with the control-specific minimal coordinates.

Abstract ID: 373

A Robust Collision Detection Algorithm for Flexible Systems Using Curve-Based Representation

Dai, Xu[1]; Kövecses, József[1]; Teichmann, Marek[2]
[1]McGill University, Canada; [2]CM Labs Simulations, Canada

As a prerequisite of contact modelling, collision detection determines the necessary geometric information of contact, which can directly influence the contact model accuracy and hence the simulation performance. Collision detection can be more complicated for flexible bodies as their shapes keep changing during simulation. In our previous work, a curve-based collision detection method has been proposed, which uses a consistent geometric representation in collision detection as in dynamic formulation, making it naturally more accurate. In this work, more details of the curve-based geometric representation are introduced. Furthermore, a general and robust multi-point algorithm is proposed to determine the contact status between curves, which solves the penetration issue under special circumstances.

Abstract ID: 374

Accessible Elastic Multibody Modeling of a Pick-and-Place Robot

Hoschek, Sebastian[1]; Rodegast, Philipp[1]; Frie, Lennart[1]; Pfeifer, Denis[1]; Scheid, Jonas[2]; Schumacher, Ruben[2]; Fehr, Jörg[1]
[1]University of Stuttgart, Germany; [2]PREMIUM ROBOTICS GmbH, Germany

Simulation technology is gaining increasing importance for small and medium-sized enterprises, although elastic multibody systems remain a challenge. To address limited financial resources and development time, an enhanced modeling workflow is presented. The deflections and vibrations of a newly developed pick-and-place robot are simulated for model-based control.

Abstract ID: 375

Optimization and Optimal Control of a Tilting Vehicle with Flexible Parts

Dopico Dopico, Daniel[1]; Lopez Varela, Alvaro[2]; Luaces Fernancdez, Alberto[1]; Garcia Orden, Juan Carlos[3]
[1]Universidade da Coruña (Spain); [2]Centro Mixto de Investigacion Navantia-UDC (Spain); [3]Universidad Politecnica de Madrid (Spain)

The kinematic and dynamic optimization of complex multibody systems opens the possibility of enhancing the design of novel and existing vehicles. In this work, the sensitivity analysis and optimization of general flexible multibody systems is described and applied to the optimization of a tilting three wheeler. The approach proposed is general and valid for any multibody system, because the general sensitivity equations are the starting point. The implementation of the equations and the numerical experiments have been built in the MBSLIM multibody library coded mostly in Fortran 2008.

Abstract ID: 377

A Tutorial on the Invariant Filtering Framework

Goffin, Sven[1]; Barrau, Axel[2]; Bonnabel, Silvère[3]; Brüls, Olivier[1]; Sacré, Pierre[1]
[1]University of Liège, Belgium; [2]OFFROAD; [3]Mines Paris — PSL

Filtering involves estimating the state of a dynamic system by integrating noisy observations with mathematical models. While the Extended Kalman Filter (EKF) is widely used for nonlinear problems, it often neglects the geometric structure and symmetries inherent in many systems. The Invariant Extended Kalman Filter (IEKF) addresses this limitation by leveraging these geometric properties for improved estimation performance. This work provides a comprehensive introduction to the invariant filtering framework, using the illustrative example of estimating the pose of an IMU constrained to pendular motion. It demonstrates that kinematic constraints can be effectively modeled as noise-free pseudo-measurements within this framework. Additionally, we propose an Iterated IEKF, inspired by the Gauss-Newton algorithm, to ensure that all estimated states adhere to the imposed constraints. These methods offer a pathway to generalizing the invariant framework for estimating extended poses in multibody systems.

Abstract ID: 378

Several Continuous Contact Force Models for Impact in Multibody Systems

Nikravesh, Parviz[1]; Poursina, Mohammad[2]
[1]University of Arizona, USA; [2]University of Agder, Norway

The so-called continuous analysis is a common method to model impacts in multibody systems. The method assumes that impact causes contacting bodies to undergo local deformation in the contact region. As such, a contact force is active during the period of contact. This force can be modeled as a logical spring and damper. While Hertz spring force is used to address the elastic behavior of the impact, challenges remain in the way the damping force can be represented. Additionally, when the form of the damping force is determined, additional efforts should be made to express the damping parameter in terms of system properties. Although the Hunt and Crossley contact force model with the developed damping factors has been used in different applications, more advanced contact force models are required to address impacts in more complex problems. As such, in this paper, we discuss the determination of damping parameters for three different contact models that can describe more complex characteristics of impacts.

Abstract ID: 379

Model Predictive Control of Dorsiflexion and Plantarflexion of a Human Foot

Shakeel, Muhammad Uzair[1]; Ebel, Henrik[1]; Khair, Ra'ad M.[2]; Nemov, Alexander[1]; Finni, Taija[2]; Matikainen, Marko[1]
[1]LUT, Finland; [2]University of Jyväskylä, Jyväskylä, Finland

This study explores the dynamics and control of the human foot focusing primarily on the dorsiflexion and plantarflexion motion. The center of research is to study the Achilles tendon, which, although strong, is prone to raptures. It consists of three sub-tendons, each of which is connected to a distinct muscle. The ankle motion is simulated using the Lagrangian multiplier's method in combination Hill-type muscle model for muscle-tendon complex force calculation for soleus and tibialis anterior muscles, and controlled using both model predictive control (MPC) and proportional-integral-derivative (PID) controllers separately, for comparison. The study simulates a real experimental setup in which a human subject exerts maximum ankle force on a pedal. The results demonstrate that MPC has superiority over PID in motion control accuracy due to its ability to predict nonlinear systems efficiently. However, MPC is computationally more demanding for real-time applicability. The superior accuracy of MPC highlights its potential in analysing tendon stresses and strains. This research will support future studies on injury prevention and rehabilitation techniques and will facilitate more complex motions.

Abstract ID: 380

A Surrogate Modeling Approach in the Real-Time Simulation of Hydraulically Actuated Flexible Systems

Mohammadalizadeh, Mojtaba[1]; Khadim, Qasim[2]; Mikkola, Aki[1]; Orzechowski, Grzegorz[1]
[1]Department for Mechanical Engineering, LUT University, Lappeenranta, Finland; [2]Department for Mechanical Engineering, University of Oulu, Oulu, Finland

Accurate simulation of a mechanical system has proven to be a valuable tool in facilitating the design process. While coupling a flexible multibody system with hydraulics can enhance simulation accuracy, it also increases computational demands. This research addresses this challenge by integrating a surrogate model, which simulates the hydraulic system more efficiently, with a flexible multibody model. The covariance matrix adaptation strategy (CMA-ES) for optimization and the modally reduced nodal-based floating frame of reference formulation (FFRF) for modeling flexible components were implemented. A forestry crane was used as a case study, with two of its mechanical components selected as flexible bodies. Results indicate that the surrogate-driven flexible model closely aligns with the standard lumped fluid theory (LFT). By replacing hydraulic forces with the surrogate model, computational costs are significantly reduced while maintaining accuracy, enabling accurate real-time simulation capabilities.

Abstract ID: 381

Surrogate Models for Programmable Structures

Pieber, Michael[1]; Zhang, Zhaowei[2,3]; Manzl, Peter[1]; Gerstmayr, Johannes[1]
[1]University of Innsbruck, Austria; [2]State Key Laboratory of Robotics; [3]Shenyang Institute of Automation

In this paper we investigate compliant joints in programmable mechanical structures, focusing on six-bar linkages that enable a remote center of rotation. Compliant joints, such as circular hinges and cross-spring pivots, can be easily manufactured using 3D printing but introduce rotational axis shifts and deviations, resulting in positioning errors during self-reconfiguration. To Analyze joint behavior, high-fidelity beam finite element models were employed to capture nonlinear effects. However, their computational intensity renders them impractical for real-time applications. To address this, we developed a surrogate mechanical model using both polynomial fitting and neural networks, enabling accurate predictions with significantly reduced computational costs. Integrated into a multibody simulation framework, the surrogate model facilitates efficient trajectory planning and error correction. Applied to a nine-cell hyper-redundant manipulator, the surrogate model reduced maximum positioning errors from 2.04 mm to 45.54 μm after corrections. This approach enables real-time error correction and precise reconfiguration without requiring position measurements. Future work will focus on further enhancing computational efficiency, advancing programmable matter applications in adaptive robotics and beyond.

Abstract ID: 384

Accelerating Multibody Dynamics Simulation Using Deep Learning Surrogate Models

Manzl, Peter[1]; Humer, Alexander[2]; Khadim, Qasim[3]; Gerstmayr, Johannes[1]
[1]University of Innsbruck; [2]Johannes Kepler University; [3]University of Oulu

We present the deep-learning based method SLiding-window Initially-truncated Dynamic response Estimator (SLIDE). Deep learning techniques are applied to learn the dynamic response of flexible multibody systems with damping. By truncating the output sequence according to the damping behavior of the multibody systems, not all coordinates need to be measured for the method's input vector, which is particularly advantageous for flexible bodies. The capacity and performance of the method is demonstrated on various examples, from the Duffing oscillator to an industrial robot standing on a flexible, deforming socket. The sliding of the windows enables the method to process longer time-sequences, while still using classic feedforward neural networks, without training on long sequences. To improve applicability of the method, the damping of general, flexible multibody systems is approximated based on the linearized equations of motion. The method's computational performance is presented, where after training of the neural network, speedups of up to 20 million compared to conventional simulation are reached on a GPU.

Abstract ID: 385

The Floating Frame of Reference Formulation for Rotordynamics Applications: Limitations and Practical Solutions

Holzinger, Stefan[1]; Zwölfer, Andreas[1]; Trainotti, Francesco[1]; Gerstmayr, Johannes[2]
[1]Technical University of Munich, Germany; [2]University of Innsbruck

The floating frame of reference formulation is widely used for modeling linearly elastic flexible multibody systems. Its ability to integrate 3D CAD models meshed with finite element tools makes it an appealing choice for rotordynamics applications. However, the conventional floating frame of reference formulation fails to account for geometric stiffening, leading to a significant underestimation of resonance frequencies and compromising the accuracy of rotordynamics simulations. This study introduces a practical and efficient approach to incorporate geometric stiffening into the floating frame of reference formulation equations of motion by augmenting the stiffness matrix with a rotation-speed-dependent term. The method seamlessly integrates into existing floating frame of reference formulation implementations. Validation using a two-disk rotor and a three-bladed rotor demonstrates the proposed approach's accuracy, closely matching fully nonlinear finite element simulations. The results underscore the necessity of including the geometric stiffening correction term to achieve precise and stable rotordynamics simulations with the floating frame of reference formulation.

Abstract ID: 386

Nitsche's Method for Simulation Contact Between the Achilles Sub-Tendons

Obrezkov, Leonid[1]; Tom, Gustafsson[2]; Rolf, Stenberg[2]; Marko, Matikainen[1]
[1]LUT University, Finland; [2]Aalto University, Finland

The Achilles tendon (AT) is a complex hierarchical structure critical for locomotion, composed of three sub-tendons originating from the medial gastrocnemius, lateral gastrocnemius, and soleus muscles. These sub-tendons are independent, non-overlapping, and capable of sliding relative to each other, a property essential for healthy tendon function. Alterations in this sliding ability due to aging or disease impact tendon mechanics and overall function. While computational modeling has been valuable for understanding tendon structure-function relationships and developing treatments, the interaction and non-uniform behavior of AT sub-tendons remain poorly studied. Due to the complexity and computational cost of modeling associated with the usage of common in these task 8-node hexahedral, current models often impose constraints like limited or no sliding, which may oversimplify the dynamics. The study introduces a novel approach combining continuum beam elements based on the Absolute Nodal Coordinate Formulation (ANCF) with Nitsche's method for elastic contact problems to simulate AT sub-tendons.

Abstract ID: 387

Lab in the Loop with Large Language Models and Multibody Simulation

Möltner, Tobias; Pieber, Michael; Manzl, Peter; Gerstmayr, Johannes
University of Innsbruck, Austria

Accurately evaluating the capabilities of Large Language Models (LLMs) in domain-specific tasks, such as multi-body dynamics (MBD) simulations, remains a significant challenge. Existing evaluation methods fall short of meeting the precision and reliability required for engineering applications, and the lack of systematic frameworks further hinders progress in this area. In this work, we present the "lab in the loop", a systematic approach for evaluating the capabilities of Large Language Models (LLMs) in MBD simulation tasks. The loop operates through iterative virtual experiments, where the LLM generates validation conjectures, extracts key input-output parameters, produces simulation code, and evaluates the model based on simulation results. Each iteration assesses the LLM's performance in completing these tasks and generates valuable domain-specific datasets, which can be used for fine-tuning to enhance future capabilities. Preliminary results demonstrate the effectiveness of the "lab in the loop" in enabling fully automated execution of MBD-related tasks, including validation, simulation code generation, and model adaptation. The modular design of the loop allows for a detailed examination of functionalities represented within the loop, enabling insights into the LLM's strengths and limitations in MBD simulations.

Abstract ID: 388

Direct and Inverse Higher-Order Kinematics of Lower-Pair Chain

Condurache, Daniel; Cojocari, Mihail; Popa, Ionuț
Technical University Of Iasi, Romania

This paper introduces a new computational method that employs vector, tensor, and quaternionic calculus, as well as the properties of dual, multi-dual (MD), and hyper-multi-dual (HMD) algebra to analyze higher-order acceleration fields in lower-pair spatial kinematic chains. The relationship between the Lie group of rigid body displacements and the Lie groups of the orthogonal HMD tensor unit MMD quaternions enables the derivation of closed-form, coordinate-free solutions for both direct and inverse higher-order kinematics. We present a general approach for studying the vector field of arbitrary higher-order accelerations of rigid bodies within the kinematic chain. Utilizing the "automatic differentiation" feature of multi dual and hyper-multi-dual functions, we can obtain the higher-order derivative of a rigid body's pose without needing to differentiate the body pose with respect to time. An illustrative application involving a general 3C four-degree-of-freedom manipulator is provided to demonstrate the calculations for velocity, acceleration, jerk, and jounce vector fields.

Abstract ID: 389

Multibody Models for Quantifying and Analysing Railway Odometry System Accuracy

Buset, Alexandre[1,2]; Fisette, Paul[1]; Docquier, Nicolas[1]
[1]Université Catholique de Louvain, Belgium; [2]Alstom Belgium

To determine the position and the speed of a railway vehicles, signalling equipment relies on odometry system. The next challenges in the railway signalling industry (absolute positioning, automatic train operation, ...) have led to the use of new sensor technologies within this ecosystem, sensors that are highly dependent on the movement of the vehicle in the three directions (IMU, wheel sensors, GNSS). This extended abstract presents the elaboration of a multibody model of railway vehicle to quantify and analyse the behaviour of the odometry system. The current model allows to highlight the impact of the dynamic (rolling) effects on the behaviour of an odometry system. As a conclusion, the extended abstract highlights the next improvements targeted for the conference (i.e., better sensors, traction and braking systems simulation).

Abstract ID: 390

Boosting GPU Parallelization for Real-Time Multibody Simulations Using Leniency: Case Study of Forward Dynamics of a Planar Serial Chain

Guigon, Louis[1]; Boudon, Benjamin[2]; Mezouar, Youcef[2]; Bouzgarrou, Chedli[2]; Kecskeméthy, Andrés[1]
[1]University Duisburg Essen, Germany; [2]University Clermont Auvergne, France

With the advent and technological progress of graphical processing units (GPU), massive parallel computing has become possible, however only for simple and independent data computational schemes. In multibody dynamics, applications are yet very sparse, as the typical computations in multibody chains are highly nested and recursive. In the present work, we develop the idea of allow-

ing GPU massive parallel computing in mechanical chains simulated by single-step ODE solvers by replacing selected state variables from previous time steps into the actual integrator step such as to unlock the nested dependencies. This approach has been termed “lenient” simulation as it allows some errors in the computation of an integrator step which are negligible in comparison to the numerical error incurred by the integrator itself. Results show the speed-up and the error obtained on the GPU using lenient computations compared to exact solutions.

Abstract ID: 391

Accurate Estimation of Peak Normal Forces During Running Using a Single Foot-Mounted IMU and a Simple Free-Flight/Impact Model with Subsequent ANN Polishing

Ghiassi, Mehdi; Kecskémethy, Andrés
University of Duisburg-Essen, Germany

Peak normal ground reaction force is a key metric for assessing biomechanical load during running. Traditional methods, such as force plates and treadmills, are precise but costly, reliant on laboratories and specialized support, and overall restrictive to natural movement. Modern approaches using single, compact, and cost-effective inertial sensors offer promising alternatives, employing (a) shank acceleration correlations, (b) center-of-mass acceleration estimates, and/or (c) neural networks. Despite high average accuracy, it is known that significant variability renders current methods unreliable for identifying individual peak loads, limiting their utility in injury prevention. The proposed method addresses this gap by using a simplified dynamic model fitted with neural networks called ANN1, ANN2, and ANN3. The deviations in estimated peak force for 30 individuals running at 2.5, 3.5, and 4.5 m/s were as follows: ANN1 +0.31% ± 11.41% (mean deviation ± Bland-Altman limits), ANN2 +0.15% ± 9.21%, and ANN3 +0.11% ± 6.4%. All newly proposed methods showed significantly lower variability than state-of-the-art methods. ANN3, the best-performing method, was unaffected by speed, gender, or running pattern in terms of mean error and Bland-Altman limits.

Abstract ID: 392

Galerkin-Based Time Integration Approaches to Rigid Body Dynamics in Terms of Unit Quaternions

May, Marvin; Betsch, Peter
Karlsruhe Institute of Technology, Germany

Simulating the dynamics of multibody systems involves dealing with finite rotations, which present a key challenge in numerical mechanics due to the fact that rotations are governed by nonlinear transformations. In this contribution, we utilize a mixed variational time approach to analyze rigid body dynamics. Time integration is based on a discretization of the weak form of the equations of motion, using a finite element formulation in time. Consequently, the equations of motion assume the form of differential-algebraic equations (DAEs). Therefore, an approximation of the Lagrange multipliers is also necessary. Moreover quaternions offer an efficient way to describe rotations, avoiding singularities encountered with other representations. This procedure provides both a systematic framework for generating time-stepping methods and a possibility of a global solution over the entire time interval. The latter can be used to solve boundary value problems that require a flow of information backwards in time. This approach may serve as a foundation for addressing more advanced problems in inverse dynamics and optimal control for rigid bodies. We apply the integration scheme to representative mechanical rigid body systems to investigate the numerical properties.

Abstract ID: 393

Generic Pretrained Reinforcement Learning Agents for Multibody Systems

Weyrer, Sebastian; Manzl, Peter; Gerstmayr, Johannes
University of Innsbruck, Austria

Reinforcement Learning (RL) agents can be used to interact with multibody systems as a controller. Traditionally, learning begins tabula rasa which means that the neural networks of the agents are initialized randomly, and high computational costs may appear during training. The pretrain then finetune paradigm is a possible solution to that, well known form other machine learning branches. In the present work, the paradigm is applied to RL agents for multibody system. An agent is pretrained by interacting with various multibody systems to gather general knowledge. To enable pretraining with several multibody systems, a funnel is introduced that bridges between the RL algorithm and the multibody systems using generic quantities. In the subsequent finetuning phase, the pretrained agent is trained to solve a control task with a target multibody system. According to the paradigm, the pretraining reduces the computational costs in the finetuning phase compared to learning tabula rasa. In the present work the benefit of pretraining using various dynamic systems is investigated and ways to accelerate RL in the field of multibody systems are discussed. The goal of the work is to reduce computational cost and thus increase applicability of RL agents.

Abstract ID: 394

Multibody Model of Mechatronic Pantograph for Railway Operations of with Multiple Pantographs

Ramalho, Pedro[1]; Ambrósio, Jorge[1]; Antunes, Pedro[2]; Oliveira, Paulo[1]
[1]IDMEC - Instituto Superior Tecnico, Portugal; [2]IRR - Institute of Railway Research, University of Huddersfield, United Kingdom

The main objective of this work is to develop a control solution for the force in the air-spring actuator to improve the contact quality between the pantograph and the catenary, and ultimately increase the maximum allowable speed of the train. To achieve this, realistic simulation scenarios are considered, using a FEM catenary model based on a Portuguese railway line for normal and elevated operation speeds, and a multibody pantograph model derived from the physical prototype mounted on the train operating on such line. The multibody model is instrumental for the foreseen developments in this work, as each one of its modelling components corresponds directly to a physical feature. The simulation scenarios include both single and double pantograph operation, as many trains require more than one pantograph to supply the necessary electrical power. Given that the maximum allowable speed is typically lower in multiple pantograph scenarios, another goal of this work is to determine whether the proposed mechatronic pantographs in a double scenario can reach or even exceed the operational speed limit of a single passive pantograph operation.

Abstract ID: 395

Assessment of the Derailment Potential of Freight Wagons Due to Cyclic Top

Pagaimo, João; Magalhaes, Hugo; Infante, Virginia; Ambrósio, Jorge
IDMEC - Instituto Superior Tecnico, Portugal

Railway vehicles are subjected to various types of dynamic excitation in their interaction with the track. However, there are certain combinations of vehicle designs, loading regimes, speeds of operation, and ranges of the wavelengths of track irregularities that excite particular modes of vibration of railway vehicles. The cyclic top phenomenon is a periodical longitudinal level track irregularity, which can excite the bounce and pitch modes of the vehicle and result in the excessive unloading of the vertical wheel load to the point of derailment. Although historically associated with track sections composed of jointed track, where short sections of rail are connected to ensure their continuity, cyclic top continues to be identified by the rail safety offices as a common explanation for the derailment of rail vehicles. Notably, this particular type of longitudinal level track irregularity is not covered by the standards that govern the limits on the vehicle behaviour. Also, the authors do not find a clear method for its identification in the literature. This work aims to characterise the vehicle, operation and track conditions that maximise the potential for the derailment due to the phenomenon of cyclic top.

Abstract ID: 396

Sensitivity of Road Vehicles Handling Dynamic Behaviour to Structural Changes

Millan, Pedro; Ambrósio, Jorge
IDMEC - Instituto Superior Tecnico, Portugal

The Body-in-White (BiW) is the backbone for the structural integrity of road vehicles. The use of new materials and structural joints in the BiW requires to understand how the BiW construction affects the vehicle dynamic behavior. The finite element (FE) method allows to develop models to study the static structural deformation and vibration characteristics of components but not the tire-road interaction and the suspension elements. Flexible multibody (FMB) simulations allow considering the tire-road contact, the suspension systems, and to include the structural flexibility of components, being suitable to study how BiW construction affects the vehicle handling dynamics. Most of the works on road vehicle dynamics consider simple tubular chassis structures, or, for more complex BiW constructions, the FMB models resort to some kind of simplification of the structure. Additionally, they are not unanimous when it comes to the relevance of including the BiW flexibility into the multibody simulations of road vehicles as well as the effect of the BiW stiffness in the ride and handling behavior of the vehicles. This work incorporates a detailed BiW model in the FMB model of a luxury sports car and explores the impact of BiW design in vehicle handling dynamics.

Presenting Authors Index