TIME TABLE

TIME	Monday	Tuesday	Wednesday	Thursday	Friday
	September 2	September 3	September 4	September 5	September 6
09.00 - 09.45	Registration	Flores	Flores	Llagunes	Tasora
09.45 - 10.30	Flores	Flores	Flores	Llagunes	Tasora
11.00 - 11.45	Ambrosio	Hesch	Tasora	Ambrosio	Hesch
11.45 - 12.30	Ambrosio	Hesch	Tasora	Ambrosio	Hesch
14.00 - 14.45	Tasora	Brogliato	Llagunes	Brogliato	
14.45 - 15.30	Tasora	Brogliato	Llagunes	Brogliato	
16.00 - 16.45	Brogliato	Llagunes	Ambrosio	Hesch	
16.45 - 17.30	Brogliato	Llagunes	Ambrosio	Hesch	
18.00	Welcome aperitif				

ADMISSION AND ACCOMMODATION

The course is offered in a hybrid format, allowing participants the flexibility to attend either in person or remotely via the Microsoft Teams platform. Limited spots are available for on-site attendance and will be allocated on a first-come, first-served basis.

Registration fees:

- **On-site participation: 600.00 Euro + VAT***

Includes a complimentary bag, five fixed menu buffet lunches, hot beverages, downloadable lecture notes.
Deadline for on-site application is July 29, 2024.

- **Live Streaming Online Participation: 250.00 Euro + VAT***

Includes downloadable lecture notes.
Deadline for online application is August 21, 2024.

Application forms should be submitted online through the website: http://www.cism.it.
A confirmation message will be sent to accepted participants.

Upon request, a limited number of on-site participants can be accommodated at CISM Guest House at the price of 35 Euro per person/night (contact: foresteria@cism.it).

** where applicable (bank charges are not included) - Italian VAT is 22%.*

CANCELLATION POLICY

Applicants may cancel their registration and receive a full refund by notifying the CISM Secretariat in writing (via email) no later than:
- July 29, 2024 for on-site participants (no refunds after the deadline);
- August 21, 2024 for online participants (no refunds after the deadline).

Cancellation requests received before these deadlines will be subject to a 50.00 Euro handling fee. Incorrect payments are also subject to a 50.00 Euro handling fee.

GRANTS

A limited number of participants from universities and research centres who do not receive support from their own institutions can request a waiver of the registration fee and/or free lodging.
Requests should be sent to the CISM Secretariat by **July 2, 2024**, along with the applicant's curriculum vitae and a letter of recommendation from the head of the department or a supervisor confirming that the institute cannot provide funding. Preference will be given to applicants from countries that sponsor CISM.

For further information please contact:
CISM (Seat of the course)
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tel. +39 0432 248511 (6 lines)
e-mail: cism@cism.it | www.cism.it

Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

ACADEMIC YEAR 2024
The Del Piero Session

CONTACT MECHANICS IN MULTIBODY DYNAMICS: FROM MODELING TO APPLICATIONS

Advanced School
coordinated by

Paulo Flores
University of Minho
Portugal

Christian Hesch
University of Siegen
Germany

Udine ***September 2 - 6*** **2024**

CONTACT MECHANICS IN MULTIBODY DYNAMICS: FROM MODELING TO APPLICATIONS

The course will address the scientific topics that contribute to the mechanical and computational challenges to handle contact mechanics in the context of multibody dynamics. The reviewing of the classic theories in elastic and plastic contact, the computational algorithms for their efficient use in the framework of multibody dynamics applications, the tribology aspects characteristic of many of the mechanical systems of interest, the consequences of wear both in the response of the system and in the use of the background contact theories are just some of the aspects of relevance that justify a closer look. The application of the theories, methods and algorithms, and their inherent numerical issues, to road and railway vehicle dynamics, general mechanical systems, biomechanical and biomedical systems are just few of the areas in which the overview of the computational methods associated to contact mechanics are of major importance.

This course provides a comprehensive state-of-the-art overview of the fundamental aspects related to contact-impact events in multibody dynamics, for both rigid and flexible elements. The well-established formulations to deal with contact problems in dynamical systems and the ongoing research domains are presented and discussed with different cases of application. The course is organized around several complementary and interconnected lectures, delivered by well-known experts in each of the scientific areas addressed. A complete framework of the contact mechanics topics are provided, including constitutive laws, numerical issues, time integration, rolling contact, contact with flexible elements and with rigid elements, complementary contact formulations, penalty based contact formulations, finite element contact, application in vehicle dynamics, biomechanics, general mechanical systems, etc.

This framework requires a computationally efficient implementation of the contact detection with regards to the contacting surfaces using different search algorithms for various sizes of contact problems. The interaction between the system components is addressed alternatively via both non-smooth mechanics formulations, penalty formulations or augmented Lagrangian approaches. The particular issues associated with the contact detection between finite element meshes, used to model flexible multibody components, is also the focus of more specialized methodologies.

The characterization of the normal and friction forces is also focused in the description of the contact interaction. The temporal integration of the multibody systems in the presence of contact-impact becomes of particular relevance not only for the stability of the dynamic analysis process but also for its computational efficiency. The contact involving flexible multibody dynamics, in which the finite element method is used to describe the system components, or rigid bodies or a mixture of both, lead to more specialized methods when dealing with the interaction forces developed in the contact. Such issues are addressed and solutions proposed. In the process, not only constitutive laws for particular types of contact, such as rolling contact in the wheel-rail interface or for tire-road, are briefly addressed but also issues such a normal and friction force contact models are presented.
The course is designed to give an integrated theoretical, numerical and application perspective on most recent advances in contact dynamics, as well as potential future research directions in this scientific domain. With this purpose in mind, this course brings together lecturers with different background and schools of thought and for the purpose of presentation, discussion, refinement of a comprehensive work on different methodologies. The foreseen participants constitute a diverse, but consistent, group of researchers, specialists, advanced students, young faculty or post-doctoral researchers, dealing with the methodological and application aspects of contact mechanics and computational multibody dynamics. During the second day, a workshop will be organized when the participants introduce themselves and their current interests in terms of research.

PRELIMINARY SUGGESTED READINGS

Flores, P., (2022) Contact mechanics for dynamical systems: a comprehensive review. Multibody System Dynamics, 54, 127-177.

Dittmann, M., Franke, M., Temizer, T., Hesch, C., (2014) Isogeometric analysis and thermomechanical mortar contact problems. Computer Methods in Applied Mechanics and Engineering, 274, 192-212.

Tasora, A., Anitescu, M., Negrini, S., Negrut, D., (2013) A compliant visco-plastic particle contact model based on differential variational inequalities. International Journal of Non-Linear Mechanics, 53, 2-12.

Ambrósio, J., (2019) Selected challenges in realistic multibody modeling of machines and vehicles. IUTAM Symposium on Intelligent Multibody Systems - Dynamics, Control, Simulation, 33, 1-39.

Brogliato, B., (2023) Modeling, analysis and control of robot-object nonsmooth underactuated Lagrangian systems: A tutorial overview and perspectives, Annual Reviews in Control, vol.55, pp.297-337, 2023.

Febrer-Nafría, M., Pallarès-López, R., Fregly, B.J., Font-Llagunes, J.M., (2020) Comparison of different optimal control formulations for generating dynamically consistent crutch walking simulations using a torque-driven model. Mechanism and Machine Theory, 154, 104031.

LECTURES

All lectures will be given in English. Lecture notes can be downloaded from the CISM web site. Instructions will be sent to accepted participants.

INVITED LECTURERS

Jorge Ambrósio - University of Lisbon, Portugal
*6 lectures on: C*ontact analysis in multibody systems. Rolling contact mechanics and flexible multibody contact mechanics using a mixed of penalty and unilateral constraint formulations for both rigid and flexible bodies. Numerical aspects in contact-impact problems in terms of computational accuracy and efficiency. Collison detection algorithms and resolution formulations within the framework of multibody dynamics. Applications of contact-impact problems with focus on railway systems, crashworthiness problems, general machines and mechanisms of common use.

Paulo Flores - University of Minho, Portugal
6 lectures on: Contact mechanics theory, analytical methods for modeling and studying contact-impact events with friction in dynamical systems. Numerical methodologies to handle of contact-impact events under the framework multibody dynamics formulations. Regularized methods and non-smooth formulations to treat contact-impact problems. Tribology dry and lubricated in contacts for multibody dynamics. Demonstrative examples of applications will allow to highlight the key aspects related to the process of modeling contact-impact events in dynamical systems.

Christian Hesch - University of Siegen, Germany
6 lectures on: Flexible multibody dynamics, finite element contact problems, mortar methods, isometric analysis, thermomechanical problems in contacts, frictional contact formulation, large deformation in contact problems, contact in flexible and deformable bodies, energy-momentum conserving schemes in frictionless dynamic contact problems, finite-deformation phase-field approach to fracture, demonstrative and practical examples.

Bernard Brogliato - INRIA, University of Grenoble Alpes, France
6 lectures on: Multiple impact modeling, well-posedness of the contact problem, Painleve paradoxes, feedback control of systems with joint clearances, control of robot-object dynamical systems, Lagrange-Dirichlet theorem and stability of nonsmooth Lagragian systems.

Josep Font-Llagunes - Universitat Politècnica De Catalunya, Spain
6 lectures on: Contact modelling approaches in biomechanical systems. Constraint forces, constitutive (compliant) force models. Percussive dynamics, center of percussion and energy theorem in percussive dynamics. Newton's hypothesis and alternative methodologies. Contact-impact in biomechanical applications and medical devices (orthosis). Academic and clinical applications of contact-impact events.

Alessandro Tasora - University of Parma, Italy
6 lectures on: Non-smooth formulations for frictional contact problems in multibody dynamics. Numerical methods for large-scale complementarity problems. Methods for efficient collision detection: broad-phase and narrow-phase algorithms, implementation details and computational aspects. Explicit smooth/nonsmooth co-simulation using kinematic constraints. Examples, benchmarks and applications to engineering problems.