

TIME TABLE

(Registration on Monday at 8:30)

TIME	Monday September 22	Tuesday September 23	Wednesday September 24	Thursday September 25	Friday September 26
9.00 - 9.45	Zlatanov	Husty	Bohigas	Wenger	Müller
9.45 - 10.30	Zlatanov	Husty	Bohigas	Wenger	Müller
11.00 - 11.45	Zlatanov	Husty	Bohigas	Wenger	Müller
11.45 - 12.30	Zlatanov	Husty	Bohigas	Wenger	Müller
14.00 - 14.45	Zlatanov	Husty	Bohigas	Wenger	
14.45 - 15.30	Zlatanov	Husty	Bohigas	Müller	
16.00 - 16.45	Zlatanov	Husty	Wenger	Müller	
16.45 - 17.30	Zlatanov	Husty	Wenger	Müller	

ADMISSION AND ACCOMMODATION

Applicants must apply at least one month before the beginning of the course. Application forms should be sent on-line through our web site: <http://www.cism.it> or by post.

A message of confirmation will be sent to accepted participants. If you need assistance for registration please contact our secretariat.

The 700,00 Euro registration fee includes a complimentary bag, four fixed menu buffet lunches (Friday subject to numbers), hot beverages, downloadable lecture notes and wi-fi internet access.

A limited number of participants from universities and research centres who are not supported by their own institutions can be offered board and/or lodging in a reasonably priced hotel. Requests should be sent to CISM Secretariat by **July 22, 2014** along with the applicant's curriculum and a letter of recommendation by 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.

Information about travel and accommodation is available on our web site, or can be mailed upon request.

Please note that the centre will be closed for summer vacation the first three weeks in August.

For further information please contact:

CISM
 Palazzo del Torso
 Piazza Garibaldi 18
 33100 Udine (Italy)
 tel. +39 0432 248511 (6 lines)
 fax +39 0432 248550
 e-mail: cism@cism.it

Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences



ACADEMIC YEAR 2014
The Peregrine Session

SINGULAR CONFIGURATIONS OF MECHANISMS AND MANIPULATORS

Advanced School
coordinated by

Dimiter Zlatanov
Università di Genova
Italy

Andreas Müller
Shanghai Jiao Tong University
China

Udine September 22 - 26 2014

SINGULAR CONFIGURATIONS OF MECHANISMS AND MANIPULATORS

Motivation and Aims

In singular configurations, the kinetostatic properties of mechanisms undergo sudden and dramatic changes. Hence the enormous practical value of singularity analysis for manipulator design and use. Its theoretical importance stems from the critical role singularity plays in algebraic geometry and in the theory of differentiable mappings. Attendees will be introduced to milestone results, key methods, and main problems in singularity analysis. The lectures provide an overview of cutting-edge work and focus on a few advanced topics.

Main Themes

Definition. Given the importance of kinematic singularity and the vast literature on the subject, it may be surprising that one rarely encounters a clear general definition of the phenomenon. To

provide one is the course's first objective: singularity is defined rigorously and in simple terms.

Classification. Numerous singularity classifications exist. Since singularity is defined via instantaneous kinematics, the most fundamental taxonomy describes the types of degeneracy of the forward and inverse velocity problems. Finer distinctions exist for specific mechanism types, e.g., the important constraint singularities of parallel manipulators. When non-instantaneous properties are considered, other distinctions arise, such as between cusp-like and fold-like singularities, or the existence of self-motions.

Identification. One of the most practically-important problems of kinematic analysis is the explicit calculation of the singularity set. Two general methods using nu-

merical partitioning of the ambient parameter space are outlined. A powerful approach for formulating and solving symbolically the algebraic equations of the end-effector's motion-pattern and singular-poses set is studied in detail.

Avoidance. The course explores the possibility of a singularity-free workspace and the ability to escape from singularity, issues of major practical importance for the design of path planning algorithms and singularity consistent control schemes.

Singularity-set and configuration-space topology. The singularity-free-connectivity properties of the configuration space are discussed, including the fascinating cuspidal manipulators, able to change posture while avoiding singularities. Related fundamental problems of genericity and configuration-

space and singularity-set topology are explored. We examine the possibility of multiple operation modes, sometimes with strikingly different platform motion patterns, connected by constraint singularities.

Mathematical tools and formalisms.

The course is a hands-on introduction to the various analytical and computational tools for dealing with singularities. We explore screw-geometrical techniques and Lie-group-based local-analysis methods. Algebraic-geometry formulations combined with either symbolic computation or numerical methods (linear relaxations and interval analysis) are used. Topology and differential geometry provide the basis for the definitions and formulations throughout the course.

INVITED LECTURERS

Dimiter Zlatanov - Università di Genova, Italy

8 lectures on:

Definition, Classification, Identification of Singularities. Screw Systems and Singularities:

Configuration space, input and output maps, definition of singularity. Forward, inverse, and configuration space singularities. Singularity types and classes. Singularity criteria and identification. Numerical determination of singularity sets. Screw geometry and singularities. Constraint singularities as C-space singularities.

Manfred Husty - University of Innsbruck, Austria

8 lectures on:

Algebraic-geometry and Robot Singularities:

Algebraic parameterizations of displacement groups, canonical equations of a mechanism, forward and inverse kinematics. Solution methods for systems of polynomial equations. Representation of singularities in different parameter spaces. Self-motions of parallel robots. Singularity-free paths between different assemblies of parallel mechanisms. Operation modes of parallel robots and transitions between them.

Jean-Pierre Merlet - INRIA, Sophia Antipolis, France

Substituted by

Oriol Bohigas - Parc Tecnològic de Barcelona, Spain

6 lectures on:

Numerical Analysis in and Near Singularities of Parallel Mechanisms:

Geometric, algebraic, and numerical viewpoints on the singularity concept. Proximity measures to singularities. Problems with dexterity indices. Interval analysis for singularity detection. Static and dextrous workspace. Dimensional design for singularity-free workspace.

Philippe Wenger - CNRS and École Centrale de Nantes, France

7 lectures on:

Cuspidal Robots: Singularities and the global and regional properties

of a manipulator's work- and configuration spaces: Cusp-like manipulator singularities, cuspidal robots. Necessary and sufficient conditions, types of cuspidal robots. Case studies. Parallel and higher-DOF cuspidal robots.

Andreas Müller - Shanghai Jiao Tong University, China

7 lectures on:

Geometric aspect and higher-order analysis of singularities:

Lie group modeling. Kinematic control problems, accessibility algebra. Stability under geometric deformations. Escape from singularities. Generic singularities of serial manipulators. Mobility and higher-order local analysis. Second-order end-effector singularities. Singularities of end-effector curves.

PRELIMINARY SUGGESTED READINGS

D. Zlatanov, R.G. Fenton, and B. Benhabib: A Unifying Framework for Classification and Interpretation of Mechanism Singularities, *Journal of Mechanical Design*, 117(4) 566-572, 1995.

O. Bohigas, D. Zlatanov, L. Ros, M. Manubens, J-M. Porta: A General Method for the Numerical Computation of Manipulator Singularity Sets, to appear in *IEEE Transactions on Robotics*, 2013.

D. Zlatanov, I.A. Bonev, and C.M. Gosselin: Constraint singularities of parallel mechanisms, *IEEE International Conference on Robotics and Automation*, 496-502, 2002.

M.L. Husty and H.-P. Schröcker: Kinematics and Algebraic geometry, in *21st Century Kinematics*, M. McCarthy (ed.), Springer, 2012.

J. Selig: *Geometric Fundamentals of Robotics*, Springer, 2005.

J.P. Merlet: *Parallel Robots*, Springer, 2nd ed., 2005.

J.P. Merlet: Singular configurations of Parallel Robots and Grassmann Geometry, *International Journal of Robotics Research*, 8(5) 45-56, 1989.

J.P. Merlet: A Formal-Numerical Approach for Robust In-Workspace

Singularity Detection, *IEEE Transactions on Robotics*, 23(3) 393-402, 2007.

P. Wenger: Cuspidal and noncuspidal robot manipulators, *Robotica*, Special issue on Geometry in Robotics and Sensing, 25(6) 677-690, 2007.

M. Zein, P. Wenger, D. Chablat : Singular Curves in the Joint Space and Cusp Points of 3-RPR parallel manipulators , *Robotica* Special issue on Geometry in Robotics and Sensing, 25(6) 717-724, 2007.

P. Wenger: Uniqueness domains and regions of feasible paths for cuspidal manipulators, *IEEE*

Transactions on Robotics, 20(4) 745-750, 2004.

P. Donelan: Singularity-theoretic methods in robot kinematics, *Robotica*, 25(6) 641-659, 2007.

A. Müller and J.M. Rico: Mobility and Higher Order Local Analysis of the Configuration Space of Single-Loop Mechanisms, *Advances in Robot Kinematics*, J.J. Lenarcic and P. Wenger (eds.), Springer, 215-224, 2008.

A. Müller: On the Manifold Property of the Set of Singularities of Kinematic Mappings, *Journal of Mechanisms and Robotics*, 3(1) & 4(1), 2011-2012.

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.

**SINGULAR CONFIGURATIONS OF MECHANISMS
AND MANIPULATORS**

Udine, September 22 - 26, 2014

Application Form
(Please print or type)

Surname _____

Name _____

Affiliation _____

Address _____

E-mail _____

Phone _____ Fax _____

Method of payment upon receipt of confirmation (Please check the box)

The fee of Euro 700,00 includes IVA/VAT tax and excludes bank charges

I shall send a check of Euro _____

Payment will be made to CISM - Bank Account No. 094570210900,
VENETO BANCA - Udine (CAB 12300 - ABI 05035 - SWIFT/BIC
VEBHIT2M - IBAN CODE IT46 N 05035 12300 09457 0210900).
Copy of the receipt should be sent to the secretariat

I shall pay at the registration counter with check or VISA Credit Card
(Mastercard/Eurocard, Visa, CartaSi)

**IMPORTANT: CISM is obliged to present an invoice for the above sum.
Please indicate to whom the invoice should be addressed.**

Name _____

Address _____

C.F.* _____

VAT/IVA* No _____

(* Only for EU residents or foreigners with a permanent business activity in Italy.)

Only for Italian Public Companies

I ask for IVA exemption (ex law n. 537/1993 - art. 14 comma 10).

Privacy policy: I understand that data received via this form will be used only to provide information about CISM and its activities, within the limits set by the Italian legislative decree no. 196/2003 and subsequent amendments.

Complete information on CISM's privacy policy is available at www.cism.it.

I have read the "Admission and Accommodation" terms and conditions and agree.

Date _____ Signature _____