On the Singularity-free Workspace of Parallel Robots Using Interval Analysis

mmmmmmmm Hadi Farzaneh Kaloorazi[1]

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Co-supervisor: Dr. Stéphan Caro[2]
Advisor: Dr. Mehdi Fakour[1]

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University of Tehran
[2]IRCCyN, Nantes, France

Outline

1. Parallel Robots
   - Introduction
   - Kinematics and Jacobian Analysis
2. Necessity of the Research
3. Optimization
4. History of the Research
   - Publications
5. Methodology
   - Interval Analysis
6. Obtained Results
   - Maximal Singularity-free Circle
7. Ongoing Works
8. Schedule
9. Acknowledgement

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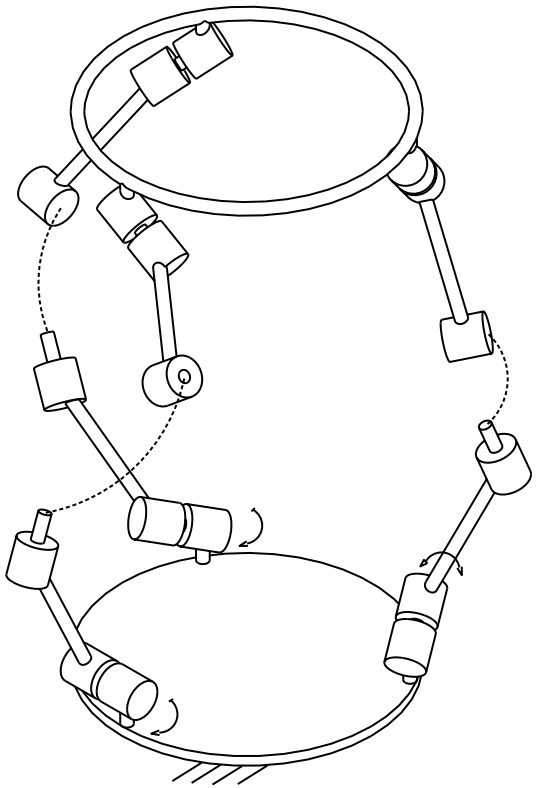
Parallel Robots

Mechanisms under study

- Parallel mechanisms (PM)
  - Planar mechanisms
  - 6-Degree-of-freedom
  - Cable driven robots

Figure presented in a thesis by Xianwen Kong



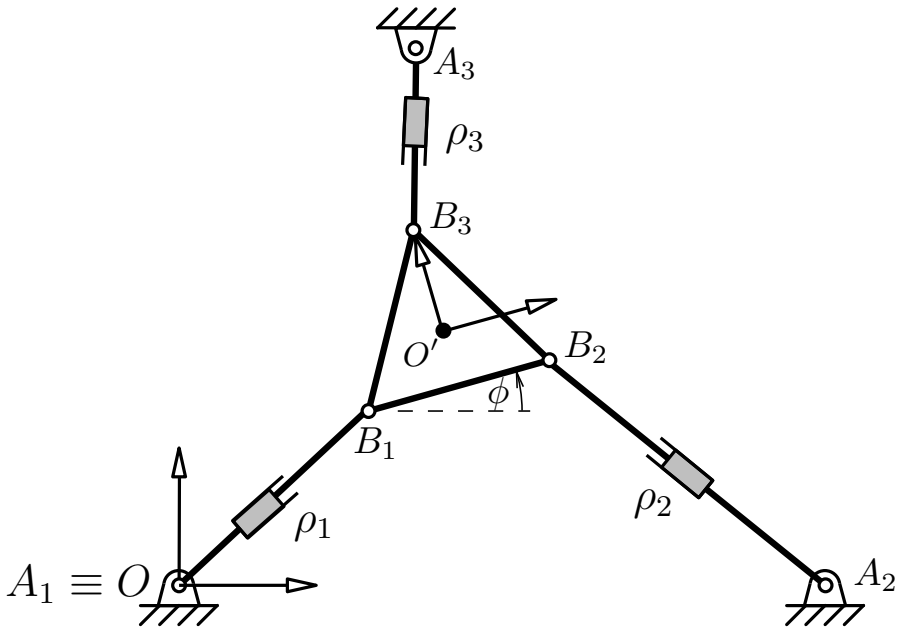
General parallel mechanism

Parallel Robots

Mechanisms under study

- Parallel mechanisms (PM)
  - Planar mechanisms
  - 6-Degree-of-freedom
  - Cable driven robots

Figure presented in a paper by Ilian Bonev



3-RPR

Parallel Robots

Mechanisms under study

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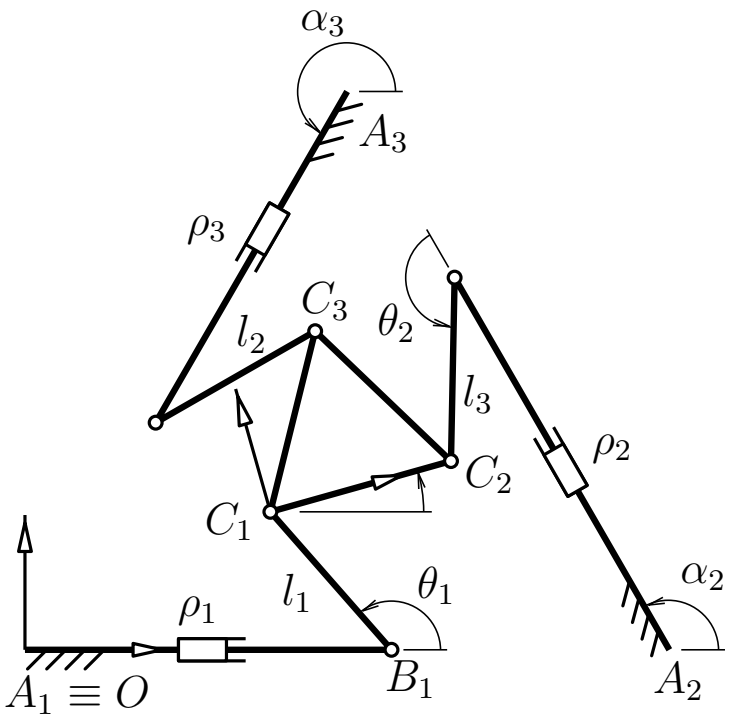

3-PRR

Parallel Robots

Mechanisms under study

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  - 6-Degree-of-freedom
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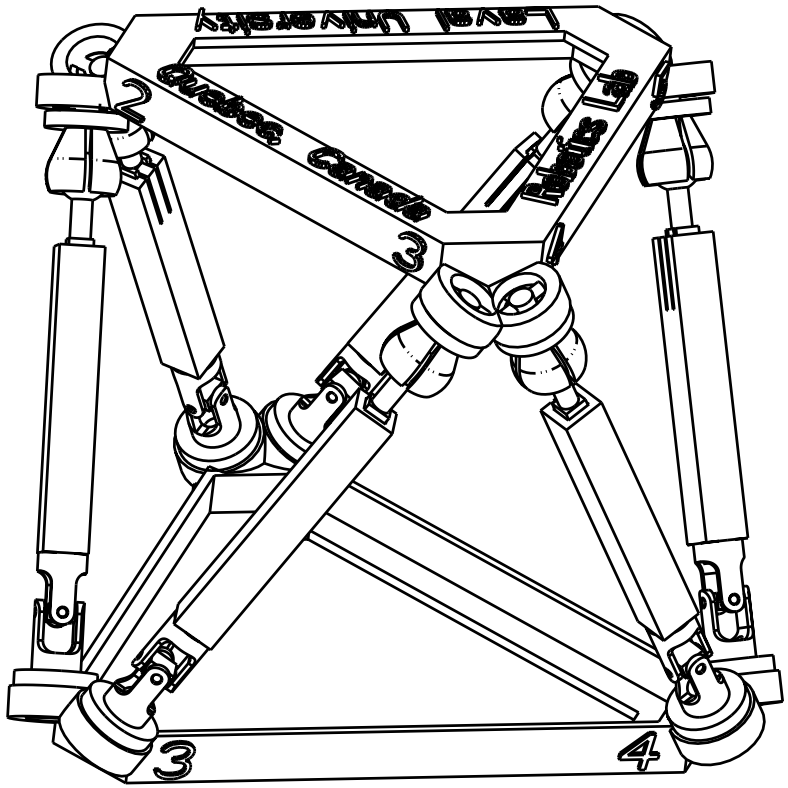
Built in Laval University



Gough-Stewart Platform (MSSM)

Parallel Robots

Mechanisms under study

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A Cable-driven robot, Arecibo Observatory in Puerto Rico

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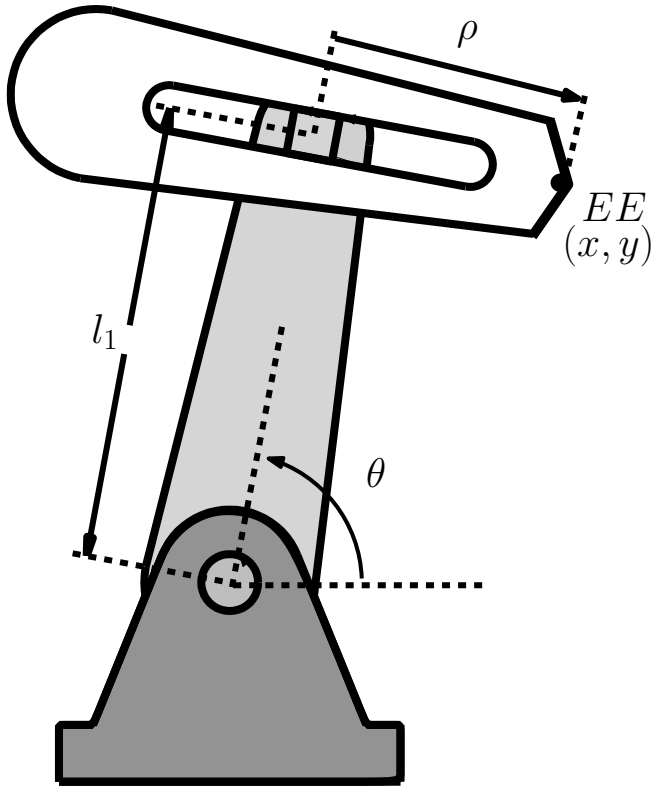
Kinematics and Jacobian Analysis

Two kinematic properties

- Workspace
  (Stroke of the actuators)
  - Serial manipulator
    2-DoF RP (joint work)
  - 3-RPR, using interval analysis
- Singularity loci
  - 3-RPR, quadratic equations
  - 3-PRR



2-DoF RP serial manipulator

Kinematics and Jacobian Analysis

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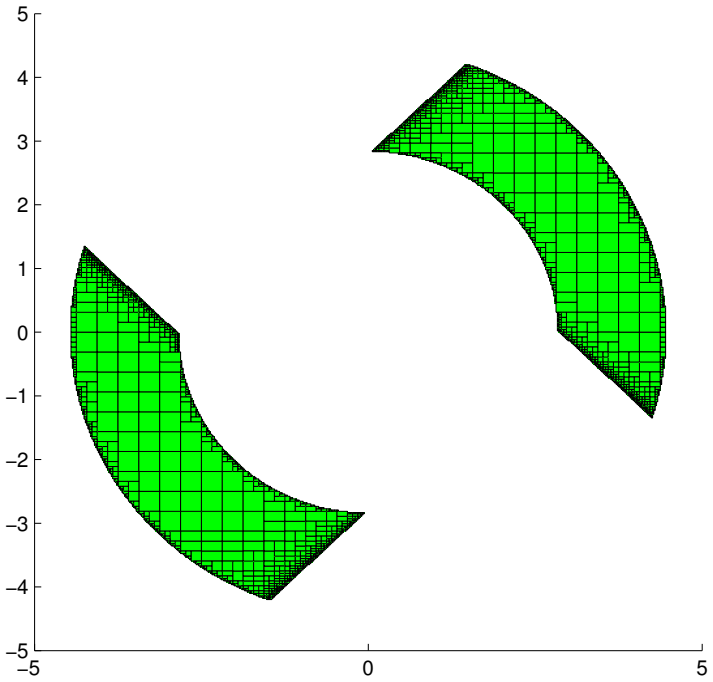

Workspace of 2-DoF RP

Kinematics and Jacobian Analysis

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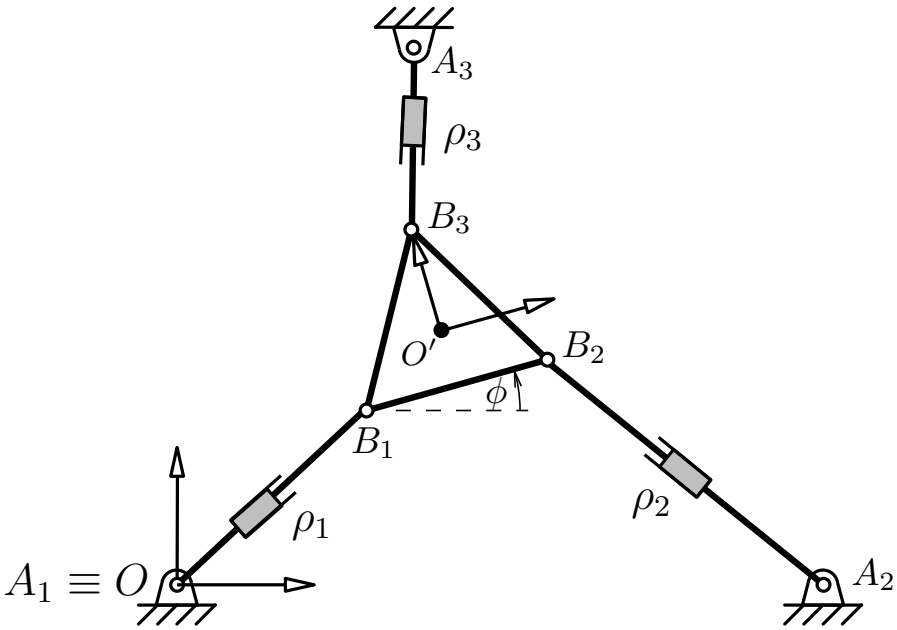

3-RPR PM

Kinematics and Jacobian Analysis

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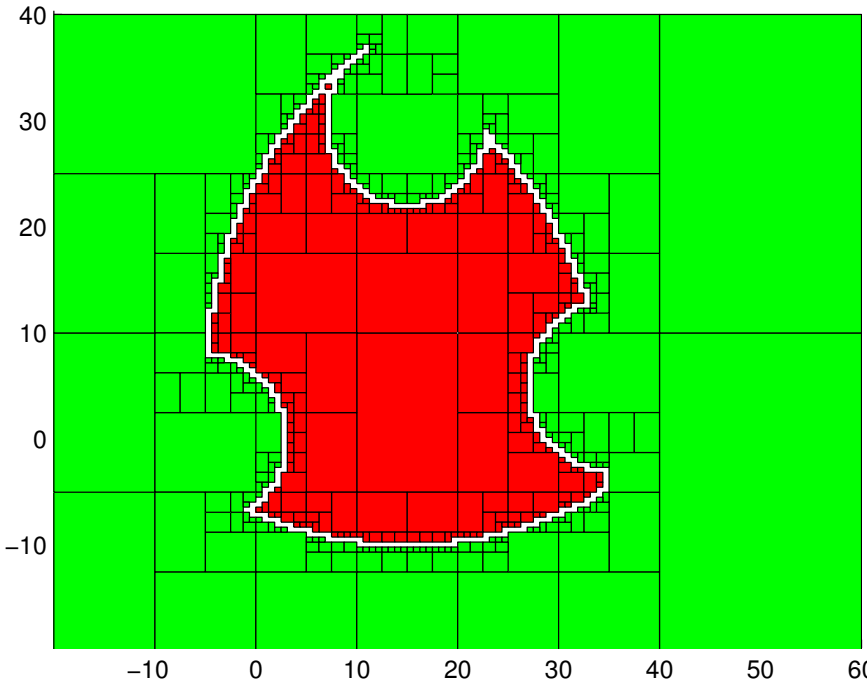

Workspace of 3-RPR PM, implemented in Matlab

Kinematics and Jacobian Analysis

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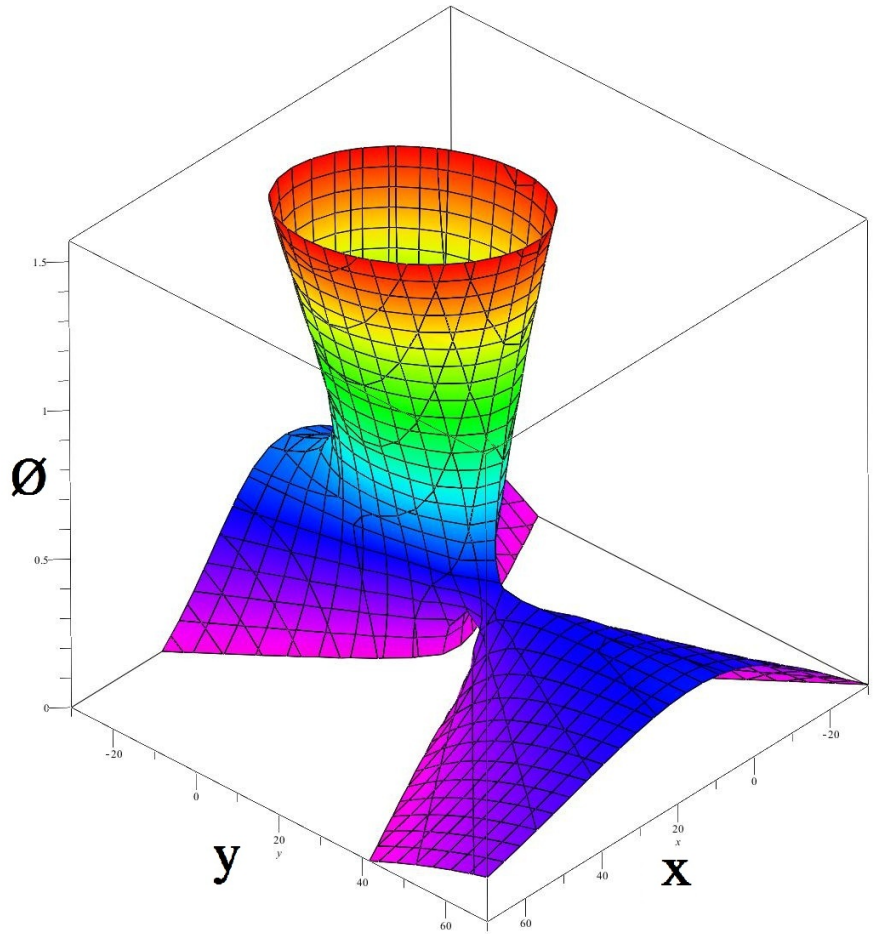

Singularity loci of 3-RPR PM

Kinematics and Jacobian Analysis

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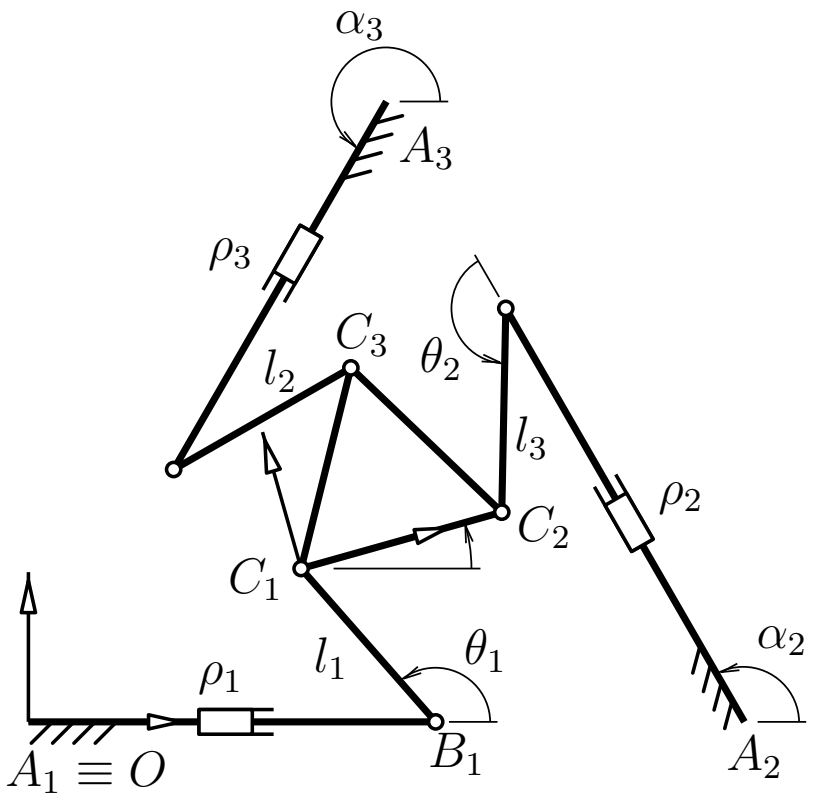

3-PRR PM

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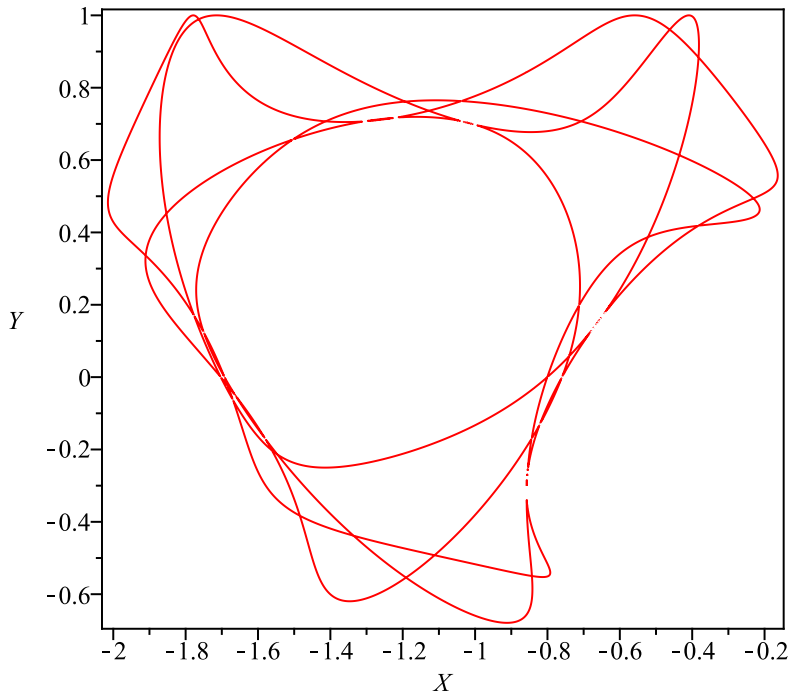
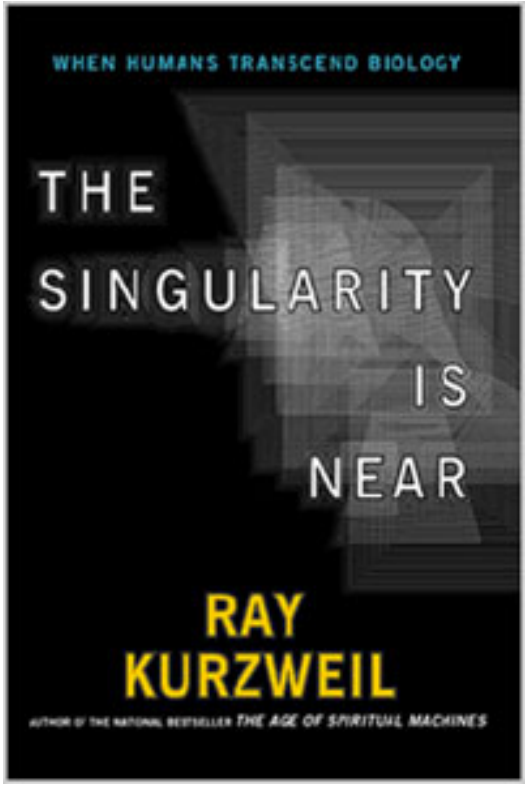


Singularity of 3-PRR PM, form implicit formulation, `ezplot`

Necessity of the research

Reliability

- The workspace of a mechanism must be singular-free
- Why circle?



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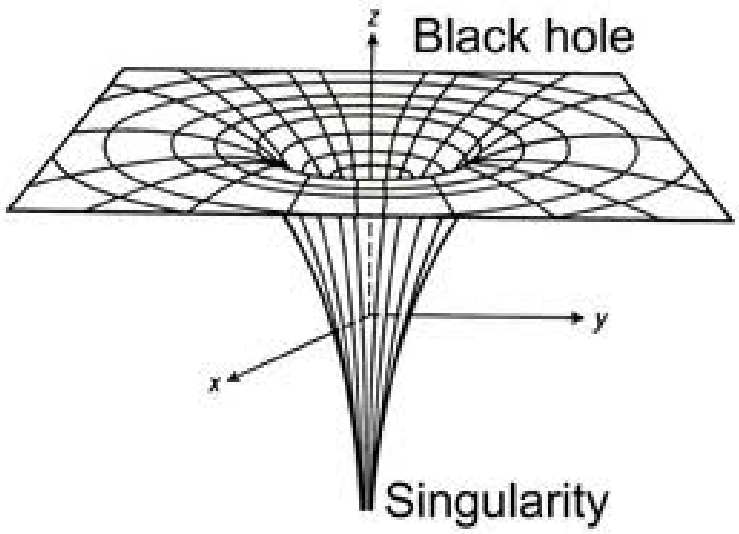

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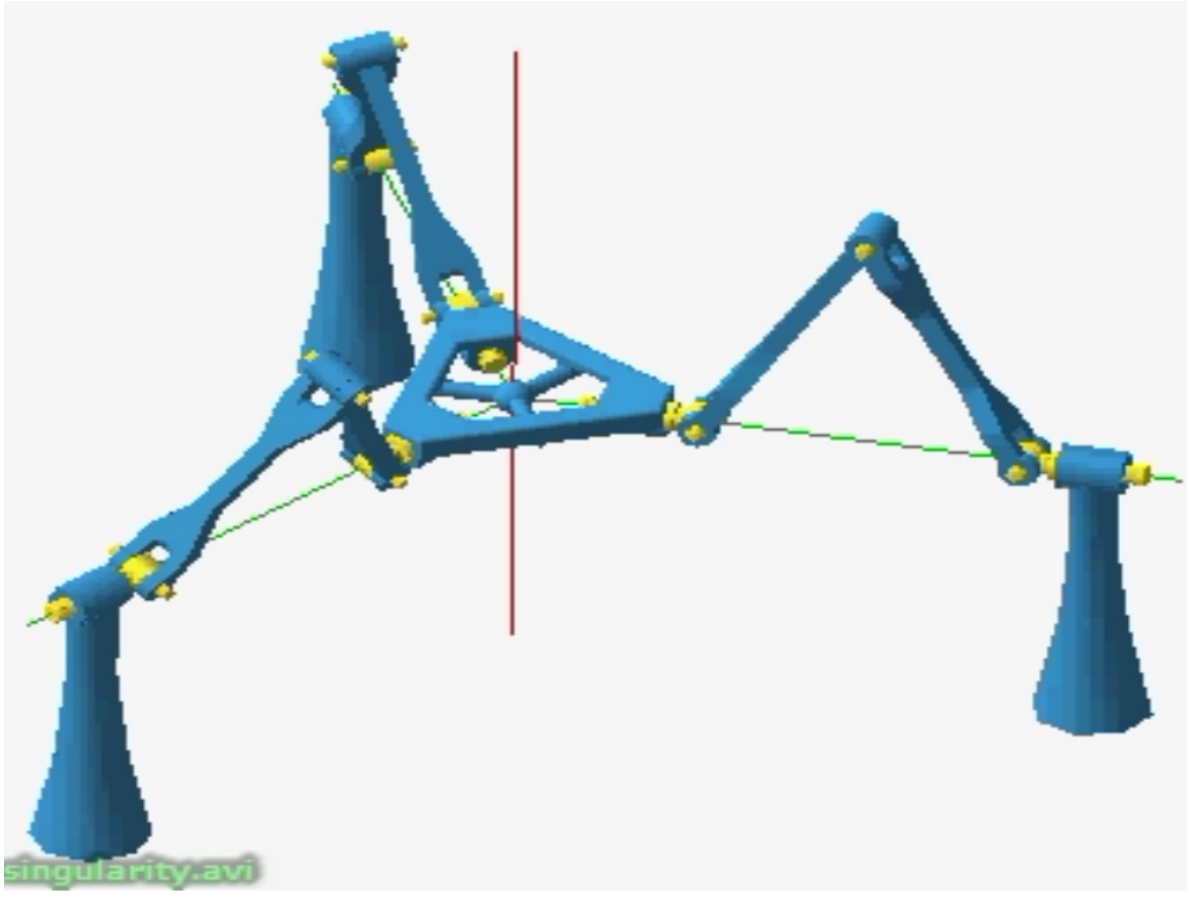
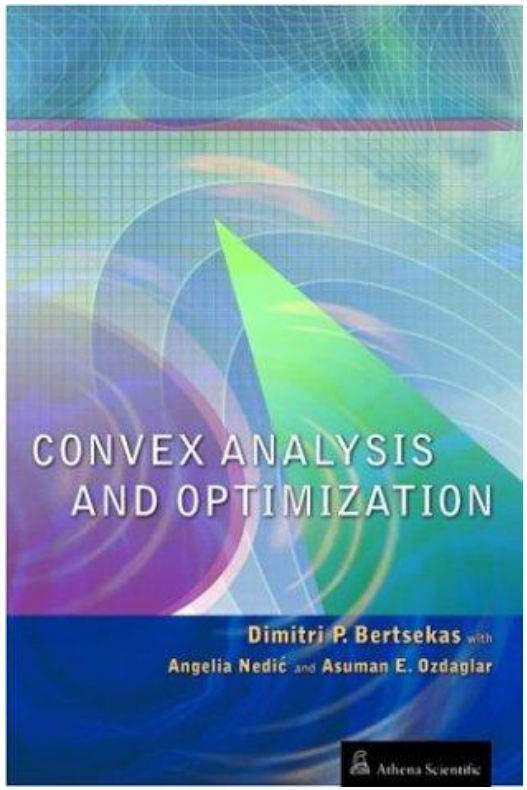


Optimization

Mathematical framework

- Convex Optimization
- *Interval Analysis*
- Other methods
  - Grid (network)
  - Offset approach
  - Evolutionary approaches



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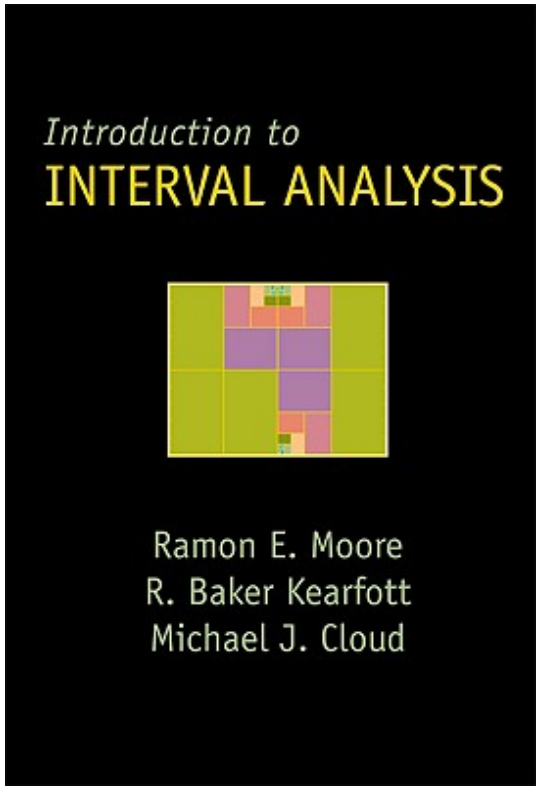

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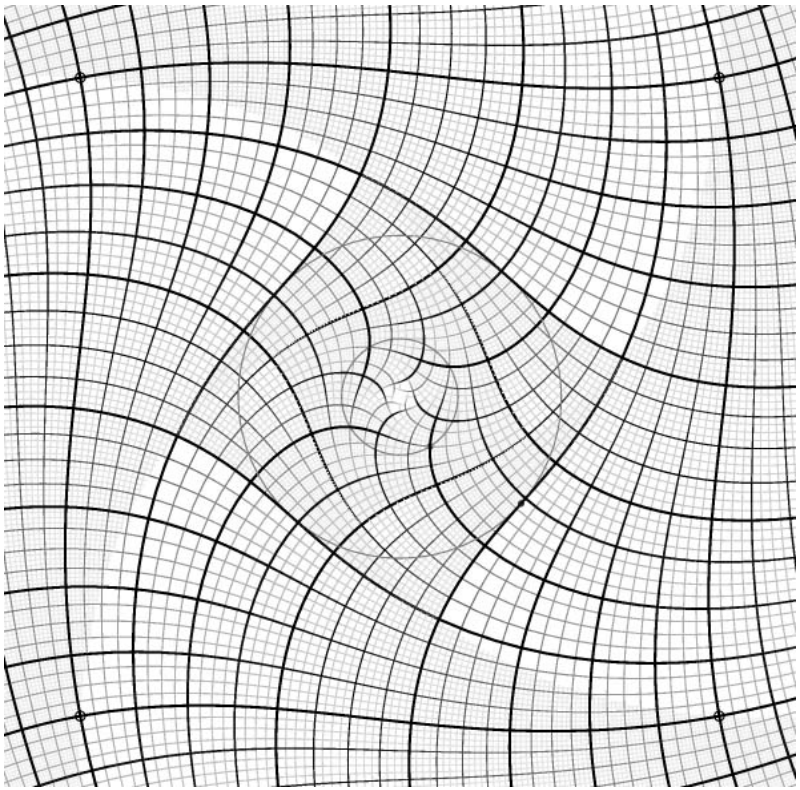

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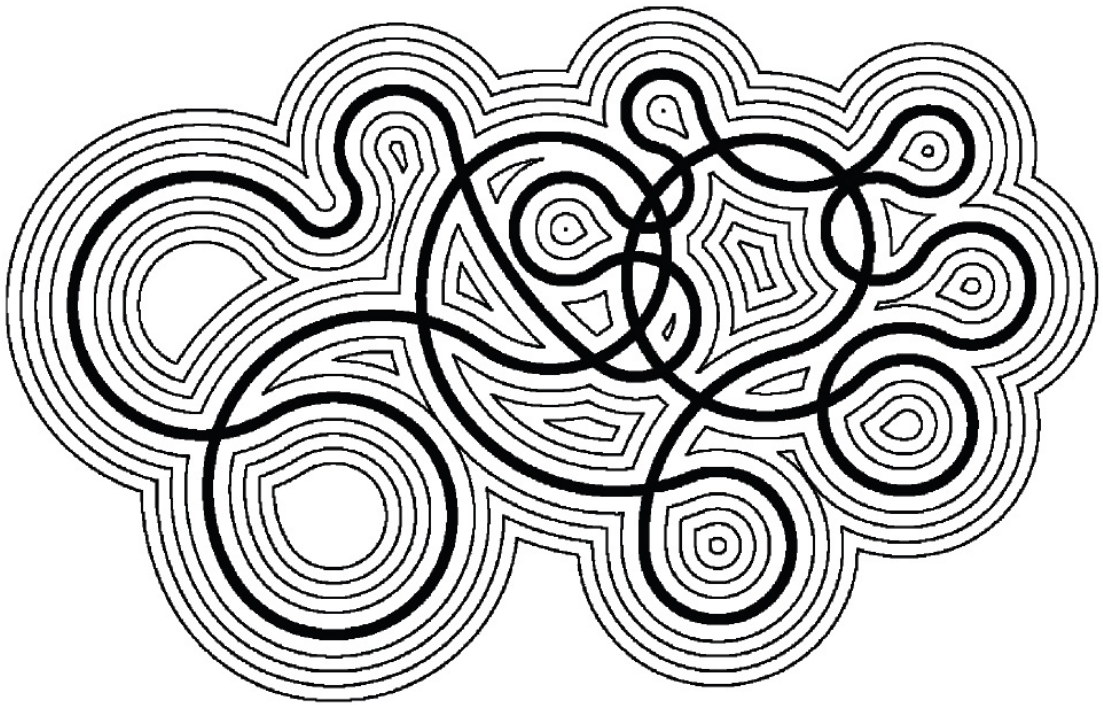

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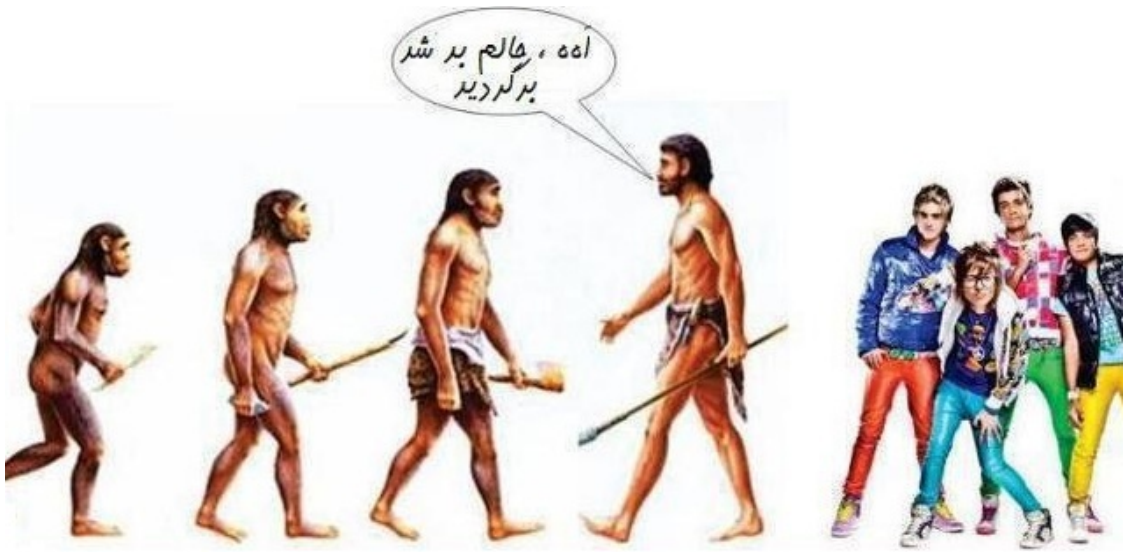

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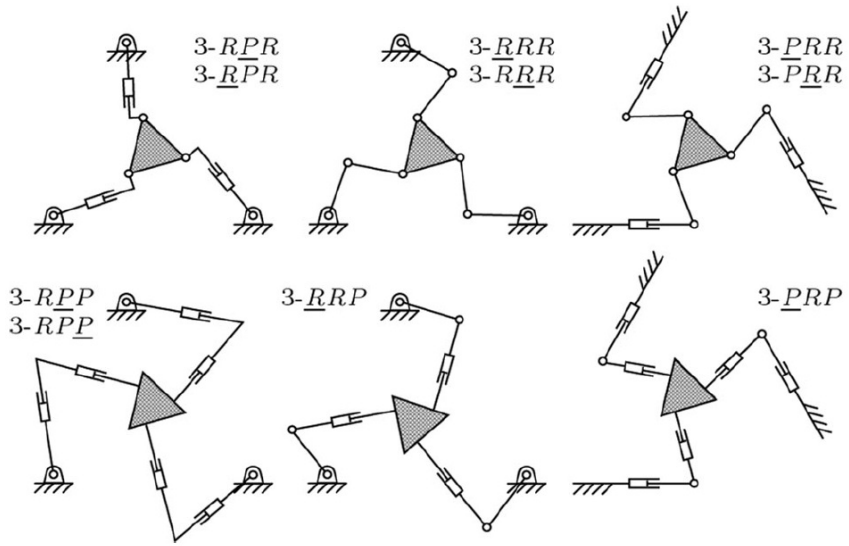
Literature

Papers

- I. Bonev, D. Zlatanov, C. Gosselin "Singularity Analysis of 3-DOF Planar Parallel Mechanisms via Screw Theory"

Method and shortage

- Lagrangian multiplier
- Fixed center point
- Only 3-R<u>P</u>R



3-DoF planar parallel mechanisms

Literature

Papers

- H. Li, C. Gosselin, M. Richard "Determination of maximal singularity-free zones in the workspace of planar three-degree-of-freedom parallel mechanisms"

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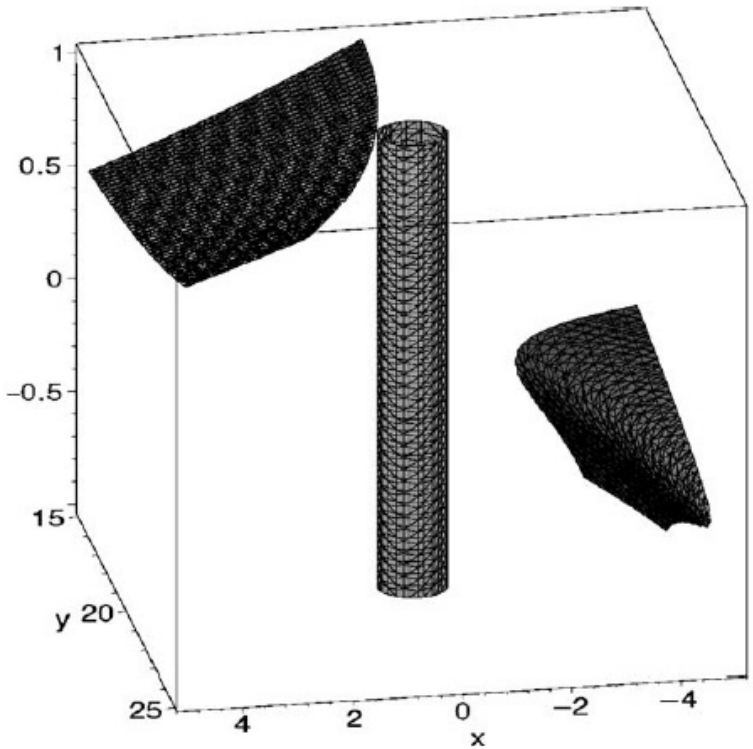

Maximal singularity-free cylinder with $\phi \epsilon [-90°, 90°]$

Literature

Papers

- H. Li, C. Gosselin, M. Richard "Determination of the maximal singularity-free zones in the six-dimensional workspace of the general Gough-Stewart platform"

Method and shortage

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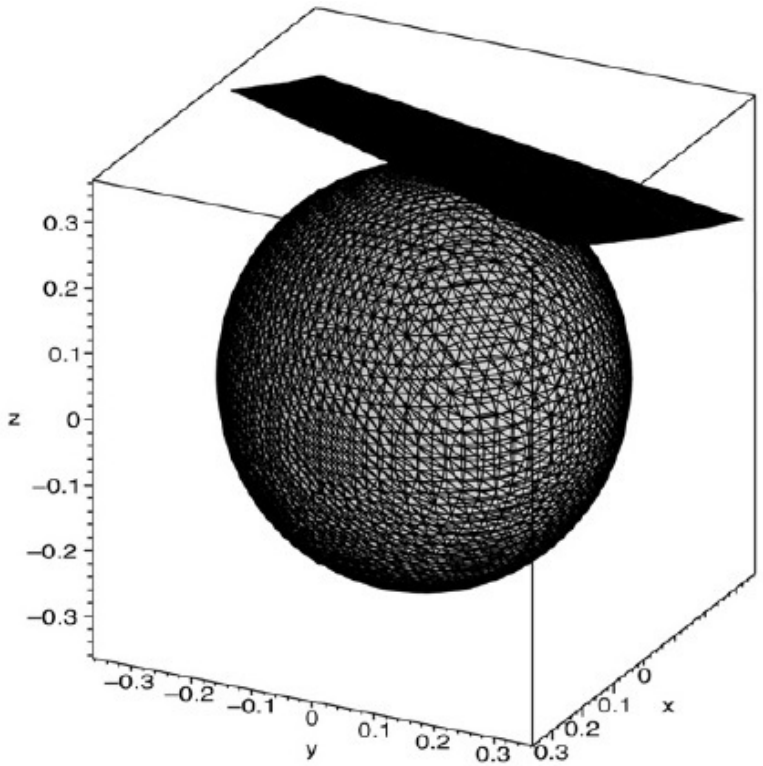

Maximal singularity-free sphere

Literature

Papers

- Q. Jiang, C. Gosselin "Determination of the maximal singularity-free orientation workspace for the Gough-Stewart platform"

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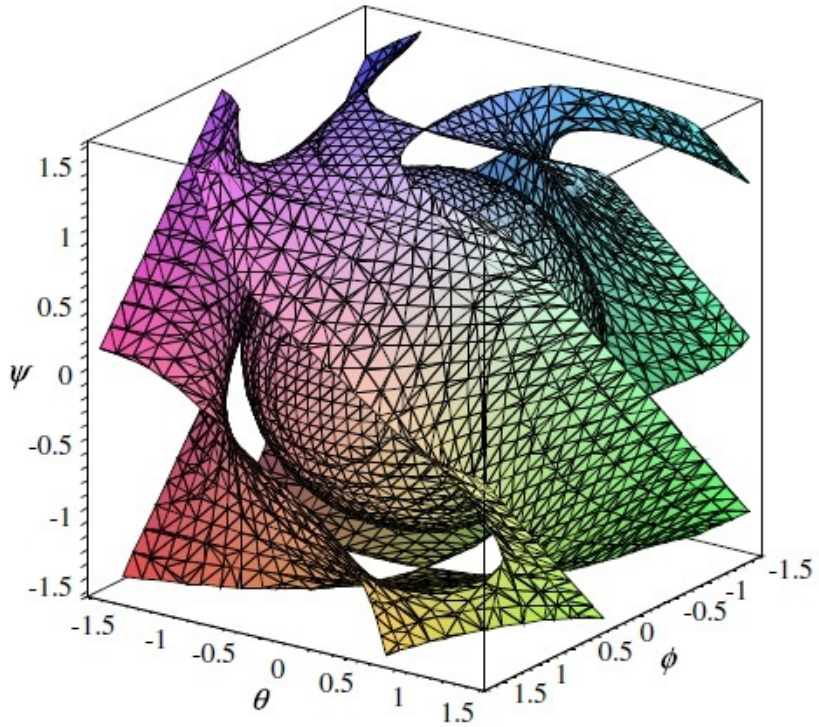

The maximal singularity sphere

Literature

Papers

- G. Abbasnejad, H. Daniali, and S. Kazemi, "A New Approach to Determine the Maximal Singularity-free Zone of 3-RPR Planar Parallel Manipulator"

Method and shortage

- Lagrangian multiplier
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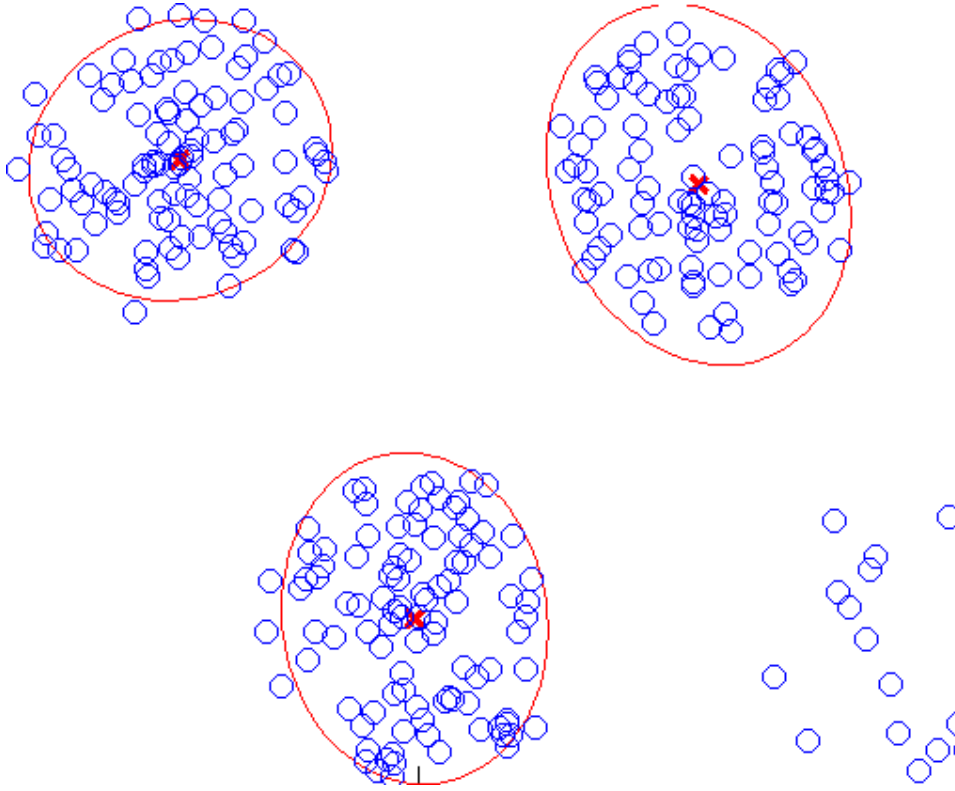
- Only 3-RPR



Particle Swarm Optimization (PSO)

Literature

Papers

- Q. Jiang and G. C.M., "Geometric Synthesis of Planar 3-RPR Parallel Mechanisms for Singularity-free workspace"

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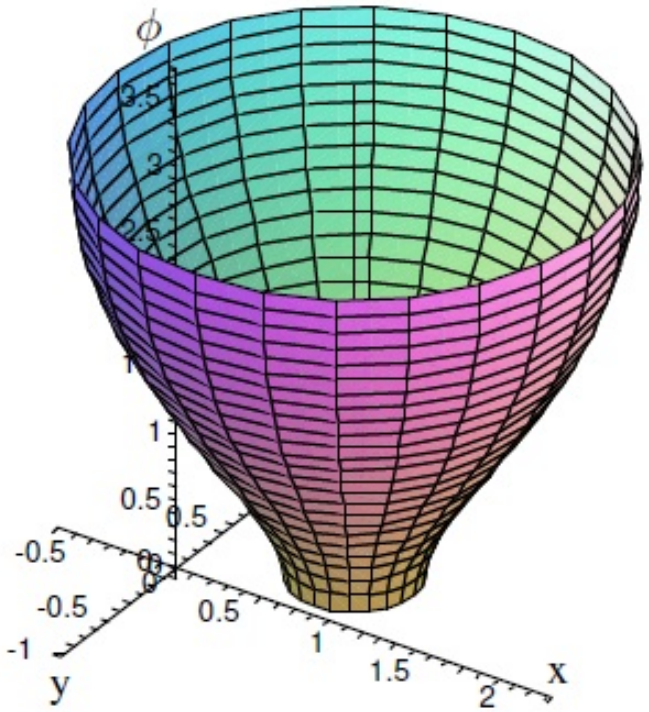

Evolution of the singularity circle vs ϕ

Literature

Papers

- Q. Jiang and C. Gosselin, "The Maximal Singularity-Free Workspace of Planar 3-RPR Parallel Mechanisms"

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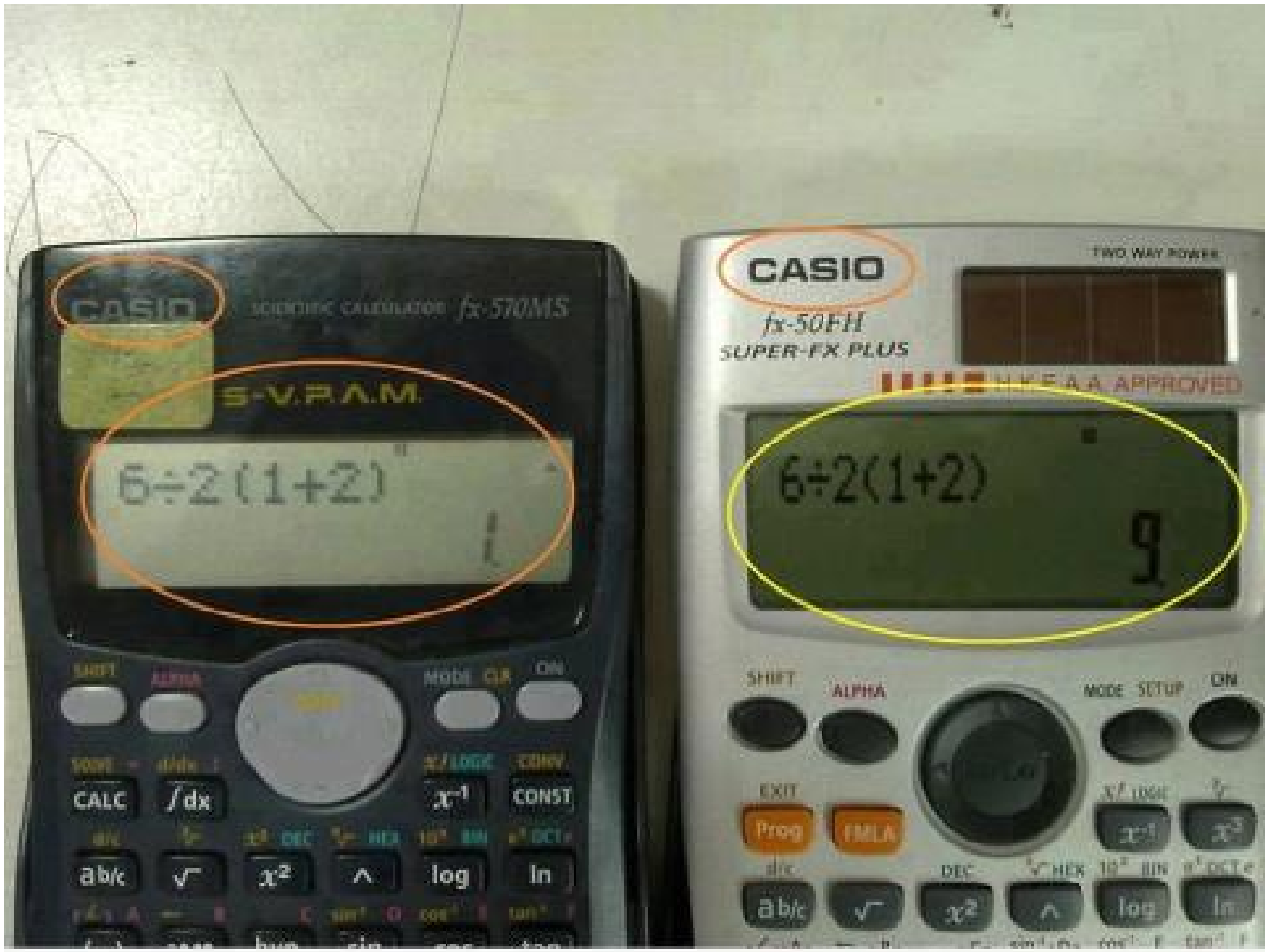
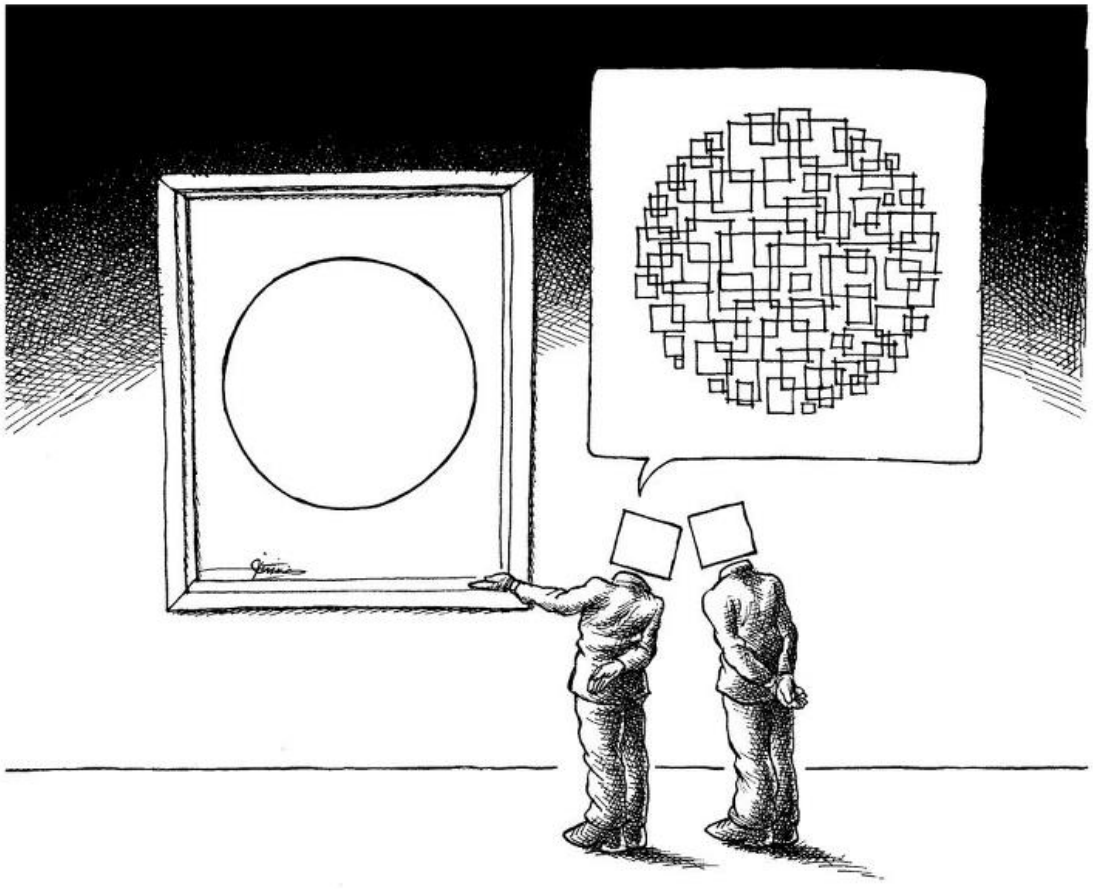
Introduction to Interval Analysis





$$f(x,y) = 333.75y^6 + x^2(11x^2y^2 - y^6 - 121y^4 - 2) + 5.5y^8 + \frac{x}{2y}$$

Matlab	Scilab	C (double)	Maple (10 Digits)	Maple (20 digits)
-1.1806×10^{21}	-1.1806×10^{21}	1.1726039	0.1×10^{28}	-1×10^{17}

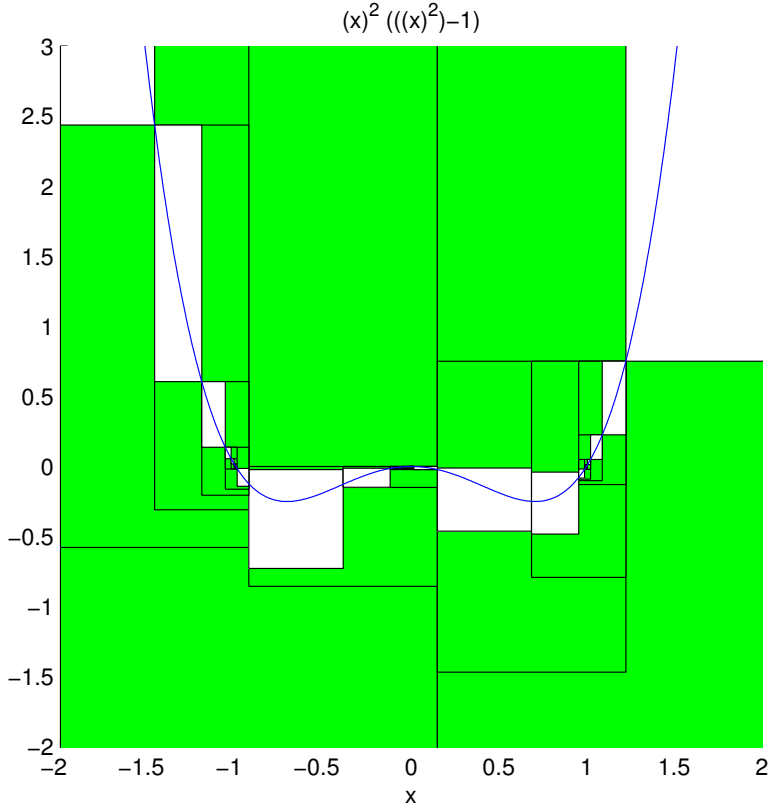
Introduction

Usages

- Finding roots of functions
- Finding extermum points
- Surfaces

Education method

Swapping teacher and student position!
Scientific negotiation!!



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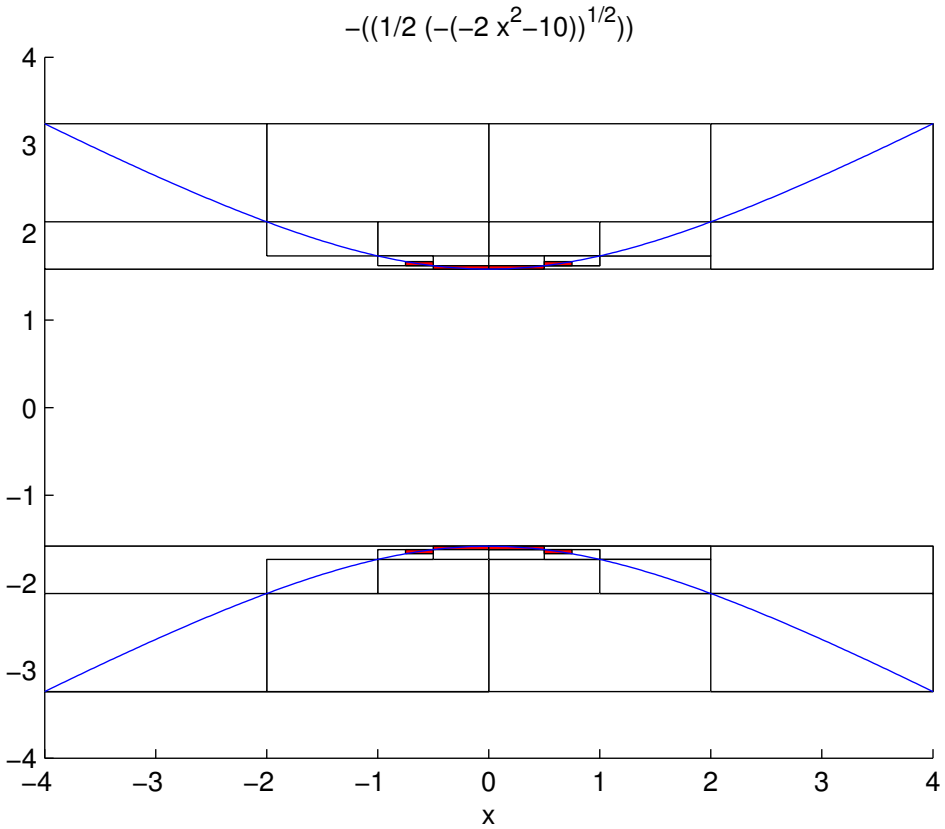

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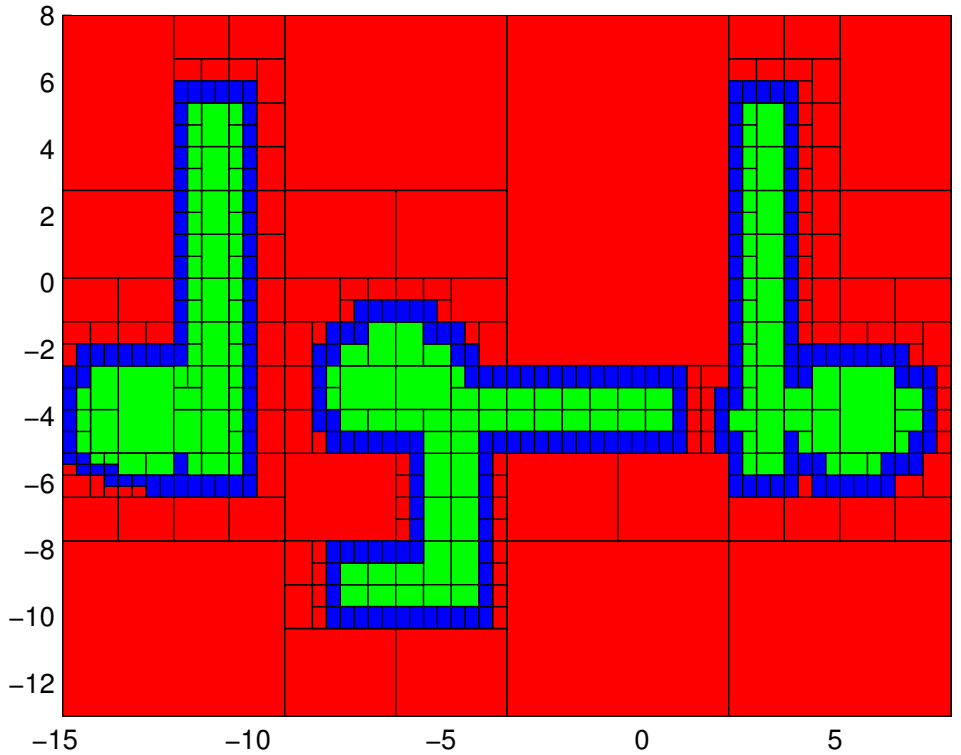

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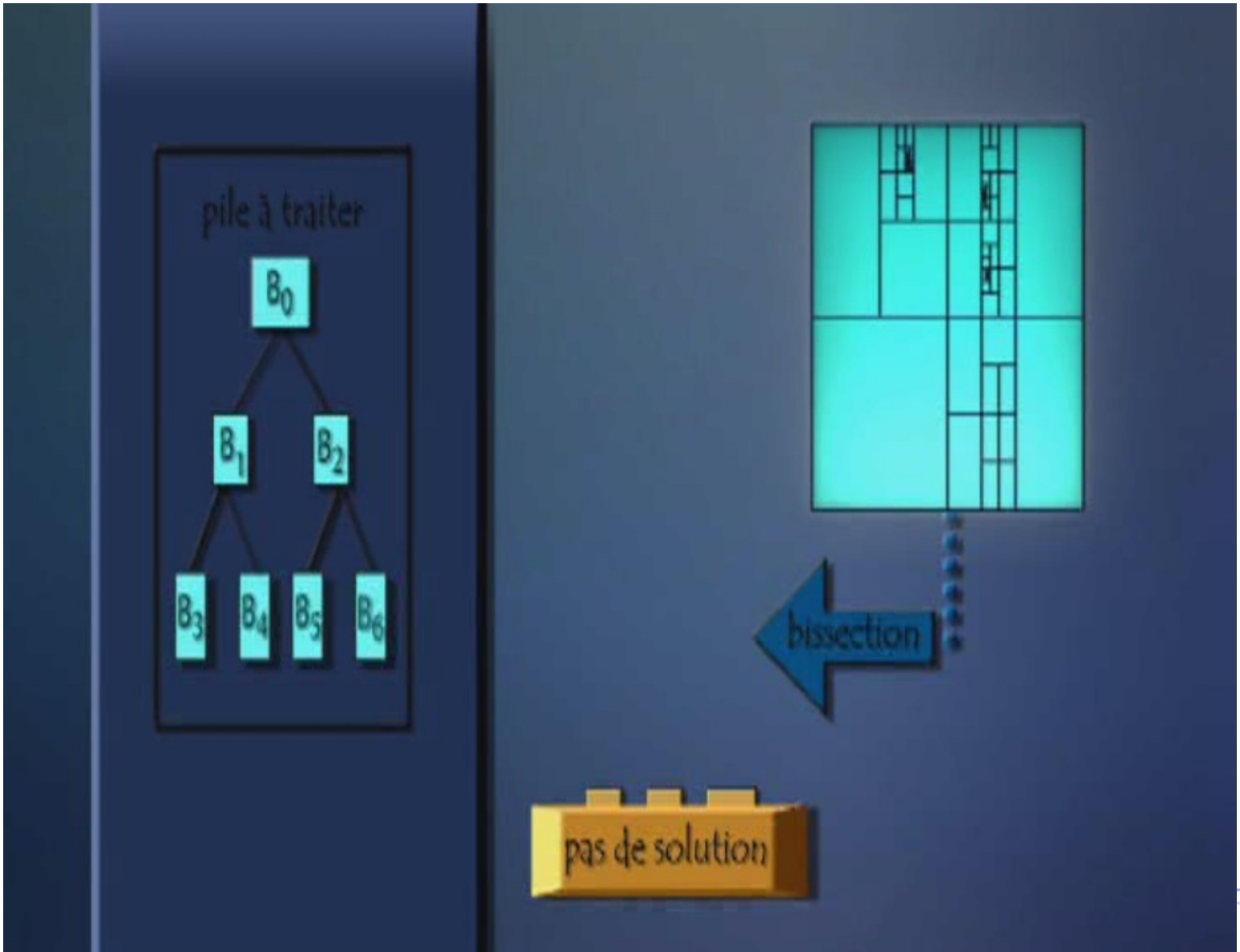
Interval Analysis Video



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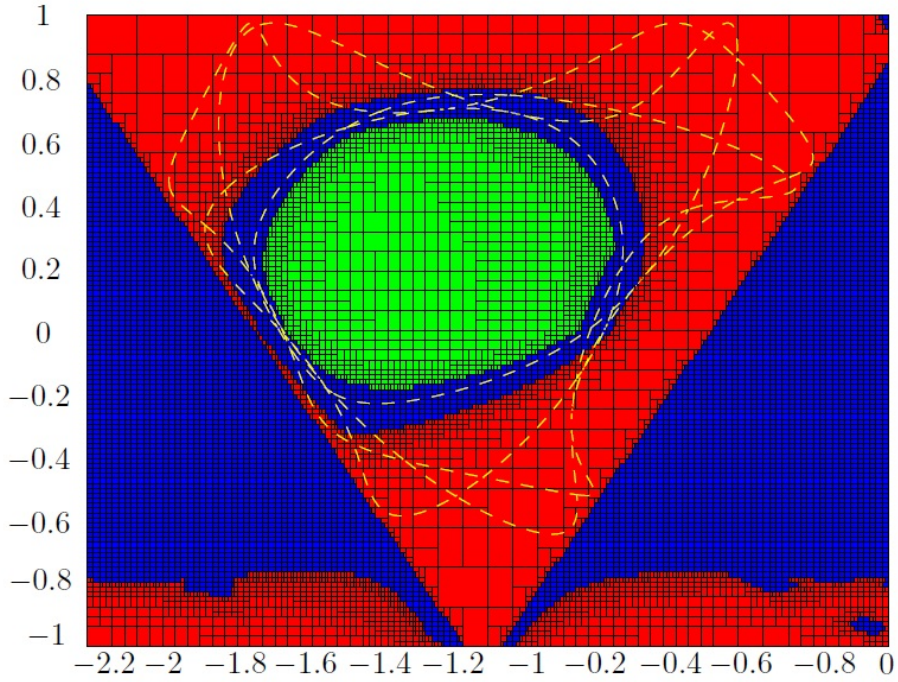
Finding Circle

Algorithm

- Fixed center
- Unknown center ⇒
  Paper submitted to ICRA 2013
  "The Maximal Singularity-free Circle of 3-RPR Planar Parallel Mechanisms Using Interval Analysis and Geometric Constructive Approach"



Singularity loci of 3-PRR

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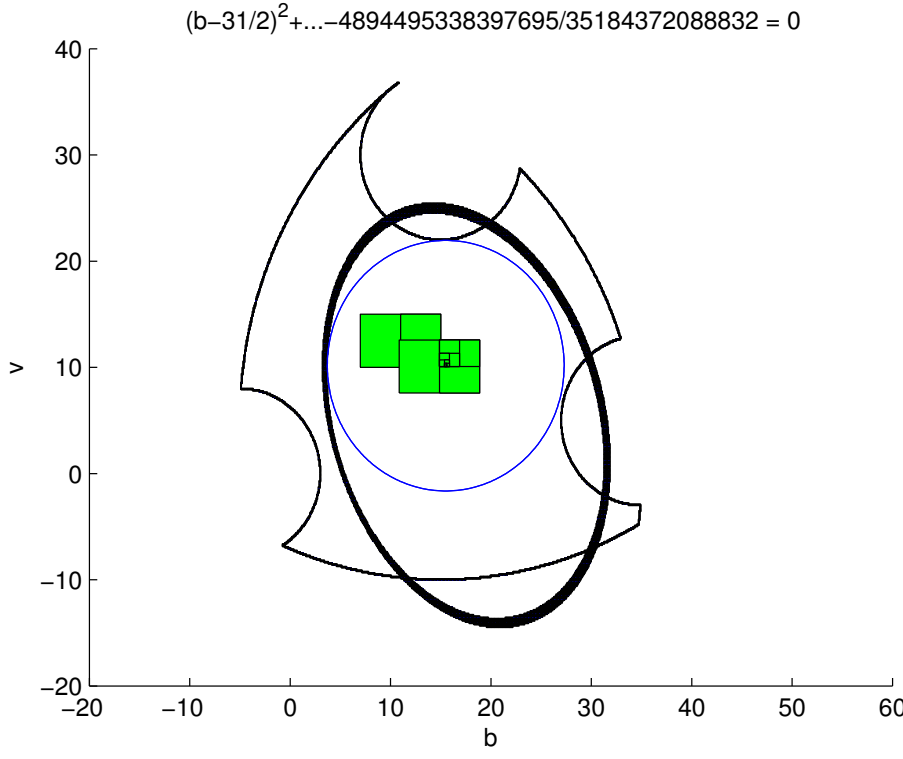
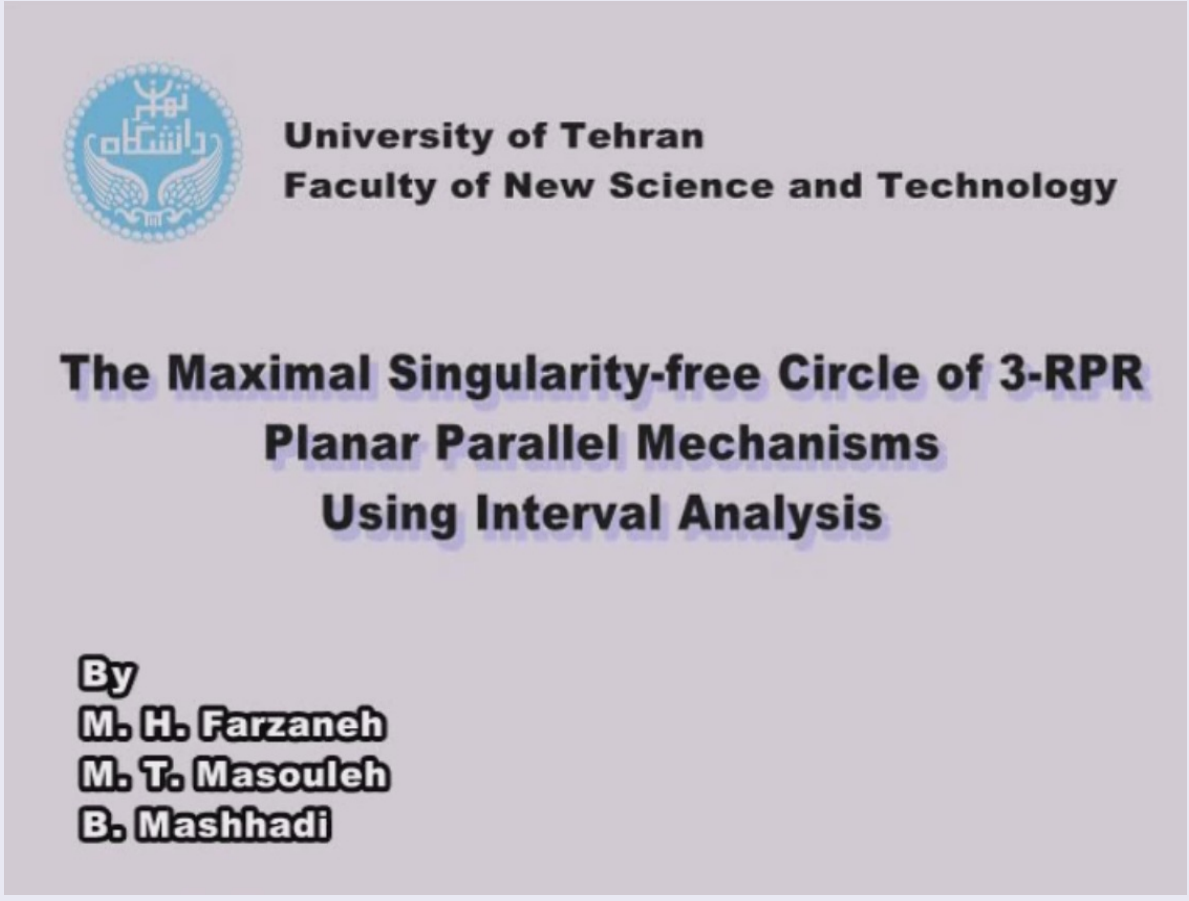


Maximal singularity-free circle of 3-RPR, by considering workspace

ICRA 2013 Paper

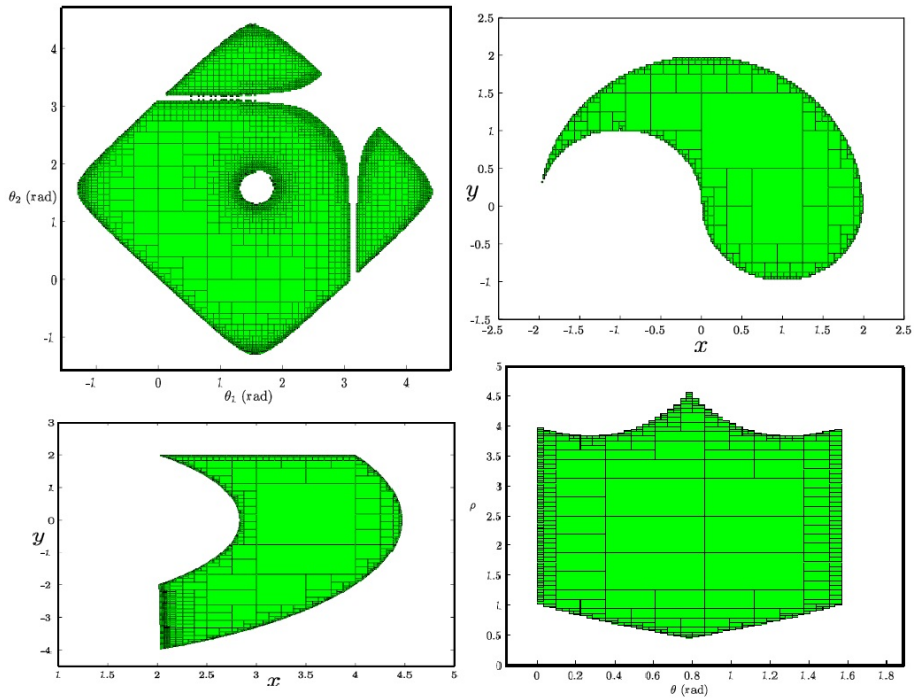
Video submitted to ICRA 2013



ICRoM 2013 Papers

Submitted papers

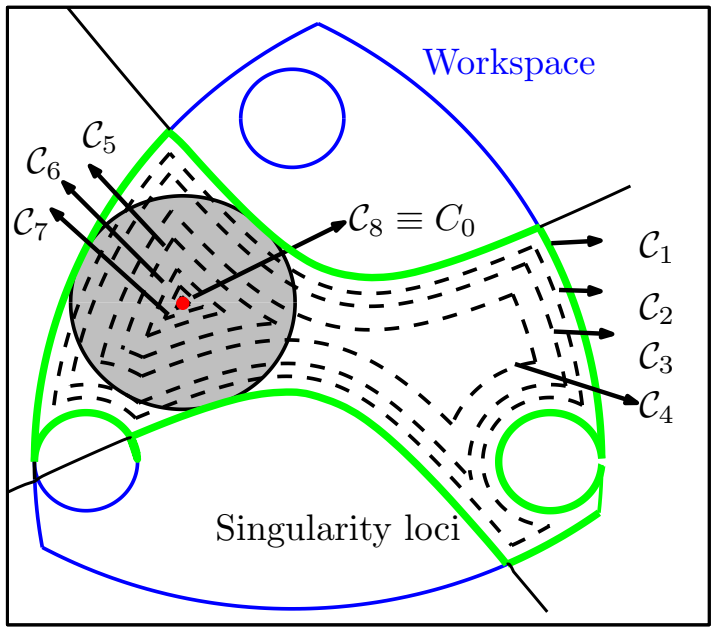
- With Mrs. Ansari, "Determining the Workspace and Joint-space of 2-DoF Serial Manipulators via Interval Analysis"
- With Mr. Mashhadi,
- With Mrs. Chaee bakhsh,
- With Mr. Behnam Mashhadi,



ICRoM 2013 Papers

Submitted papers

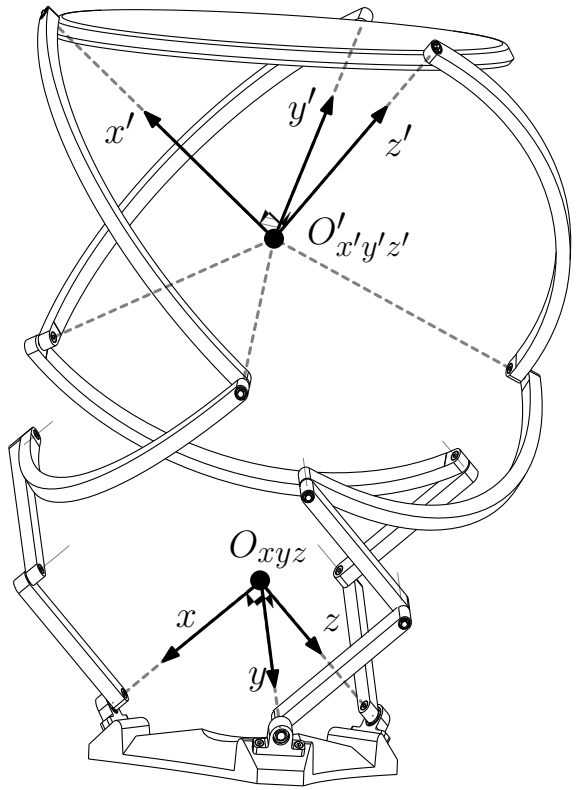
- With Mrs. Ansari,
- With Mr. Mashhadi, "The Maximal Singularity-free Circle in the Workspace of 3-RPR Planar Mechanisms Using Interval Analysis and Geometrical Approach"
- With Mrs. Chaee bakhsh,
- With Mr. Behnam Mashhadi,



ICRoM 2013 Papers

Submitted papers

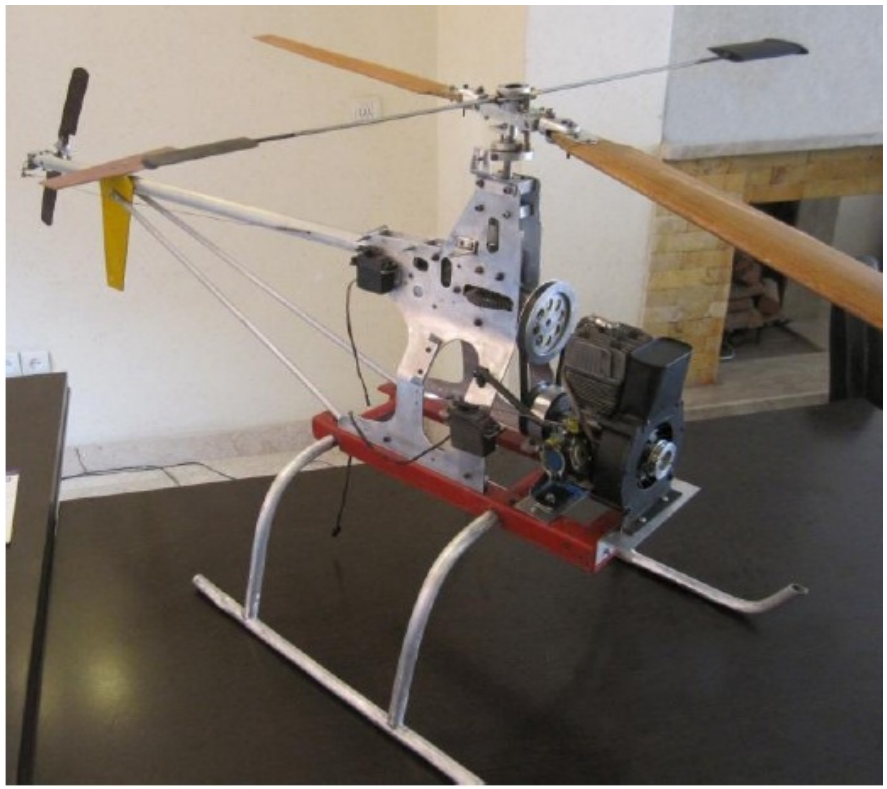
- With Mrs. Ansari,
- With Mr. Mashhadi,
- With Mrs. Chaee bakhsh, "Kinematics of a Spherical Parallel Mechanism with Identical Limb Structures Using the Linear Implicitization Algorithm and Euclidean Geometry"
- With Mr. Behnam Mashhadi,



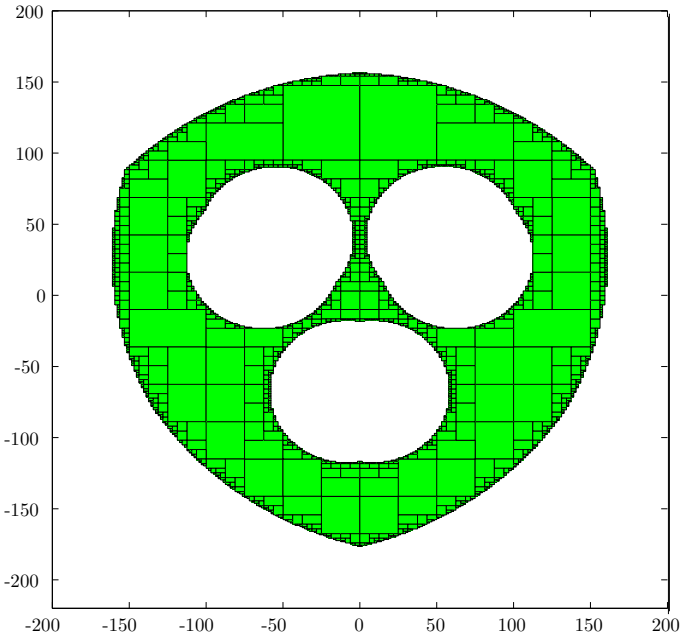
ICRoM 2013 Papers

Submitted papers

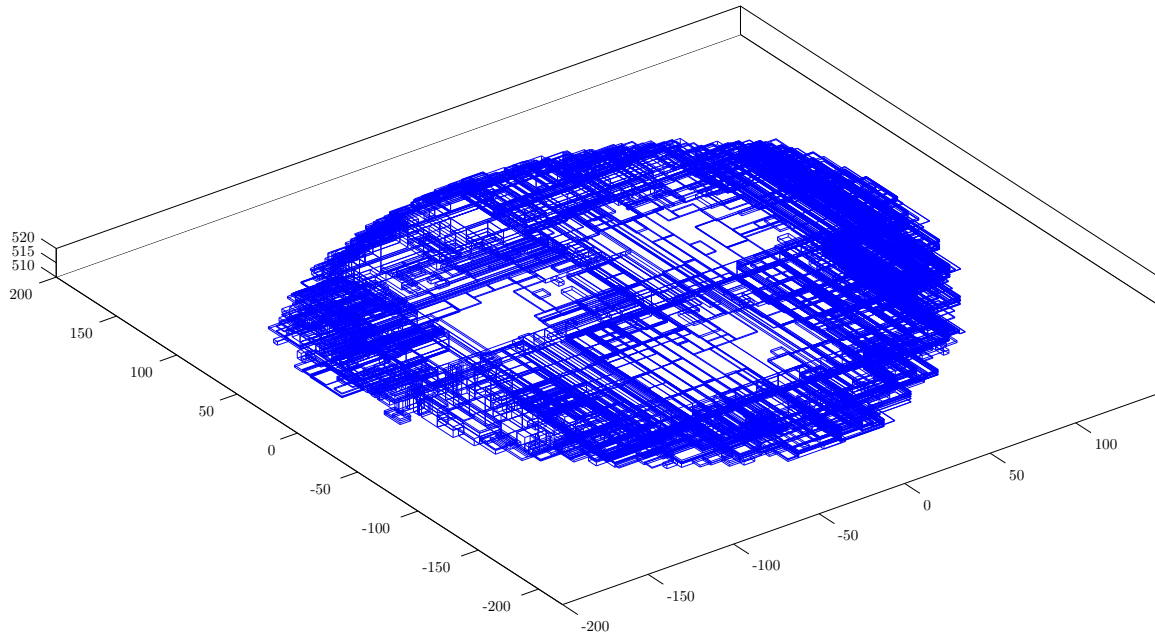
- With Mrs. Ansari,
- With Mr. Mashhadi,
- With Mrs. Chaee bakhsh,
- With Mr. Behnam Mashhadi, "Manufacturing of a UAV Helicopter"



3D Workspace of Gough-Stewart Platform



2D constant orientation workspace (COW) of Gough-Stewart platform, $z = 512$

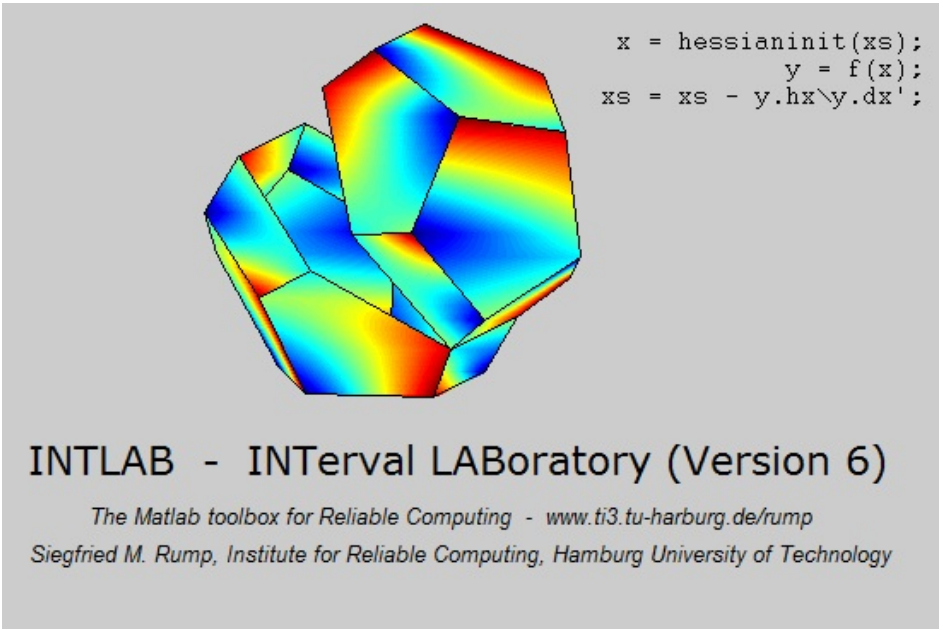


3D COW of Gough-Stewart platform, $z = [510, 520]$

Experiences On

Instruments

- INTLAB
- IntPakx
- *ALIAS*



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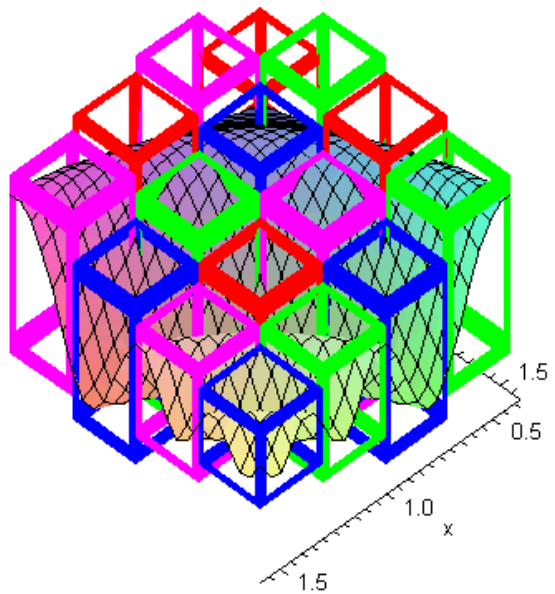

Interval arithmetic using MAPLE

Experiences On

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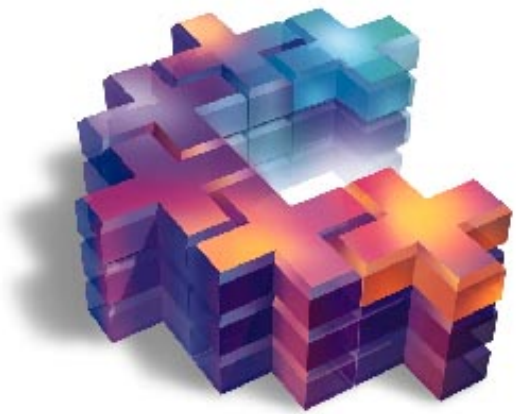


C++

MMKR 2012 International Summer School

TECHNICAL UNIVERSITY OF CLUJ-NAPOCA
FACULTY OF MACHINE BUILDING
CENTER FOR INDUSTRIAL ROBOTS SIMULATION AND TESTING (CESTER)

MMKR 2012
International Summer School
July 01 - July 08, 2012, Cluj-Napoca, ROMANIA

IFToMM

OFFICIAL CERTIFICATE

Mohammad Hadi FARZANEH
University of Tehran , Iran

attended the

Summer School on Models and Methods in Kinematics and Robotics 2012
Technical University of Cluj-Napoca, Romania

Prof. Doina PISLA
MMKR 2012 Conference Chair

MMKR 2012 International Summer School

Me, Prof. J.-P. Merlet and Prof. M. L. Husty

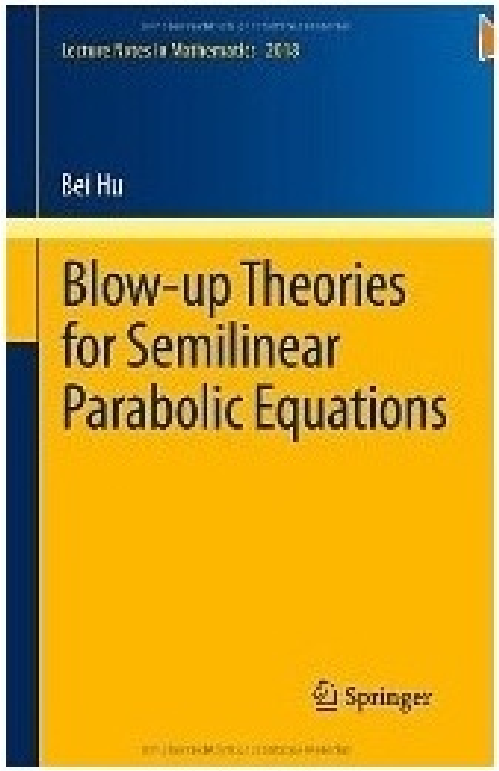
Ongoings

Obstacles

- Find maximal singularity-free for 3-PRR
  $\Rightarrow$ *Blows up*
- Cable-driven PMs
  $\Rightarrow$ *Consistency*

(cooperating with Mr. Saman Esfahani)

- Grid method applicable for more complicated singularities and deals with *dexterity*



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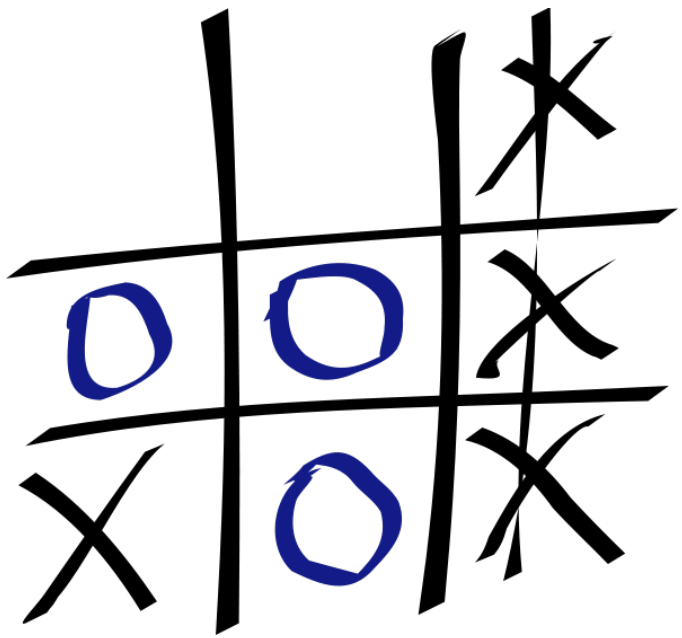
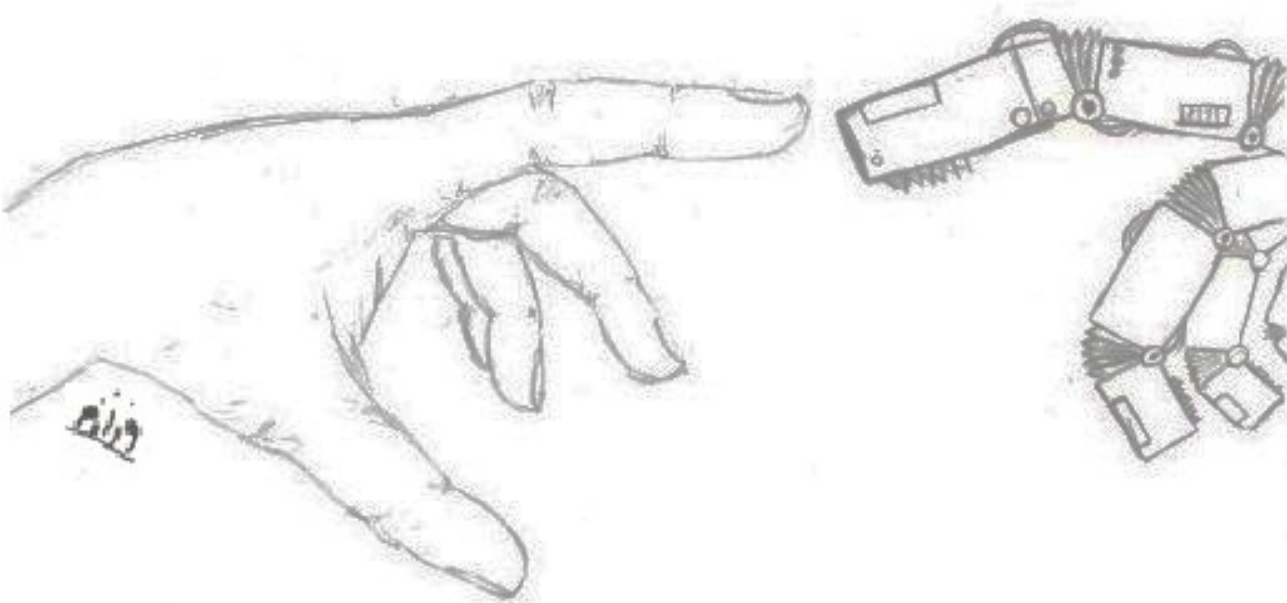


Ongoings

Future programs

- Develop offset approach
- ALIAS
- Gough-Stewart and Cable-driven robots



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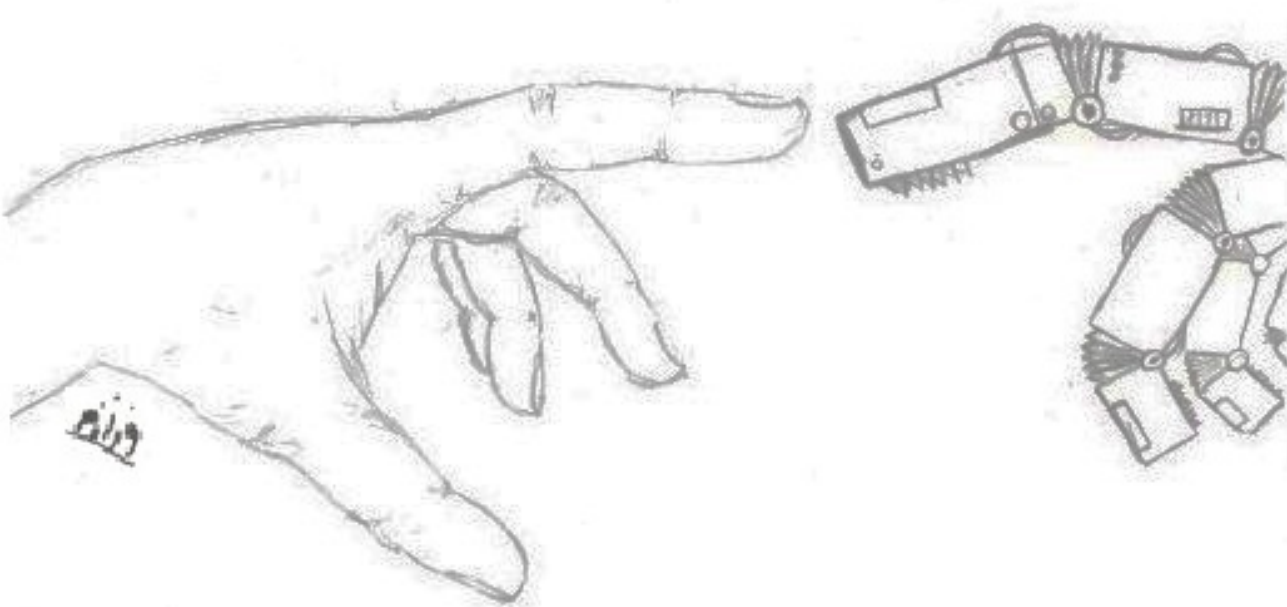

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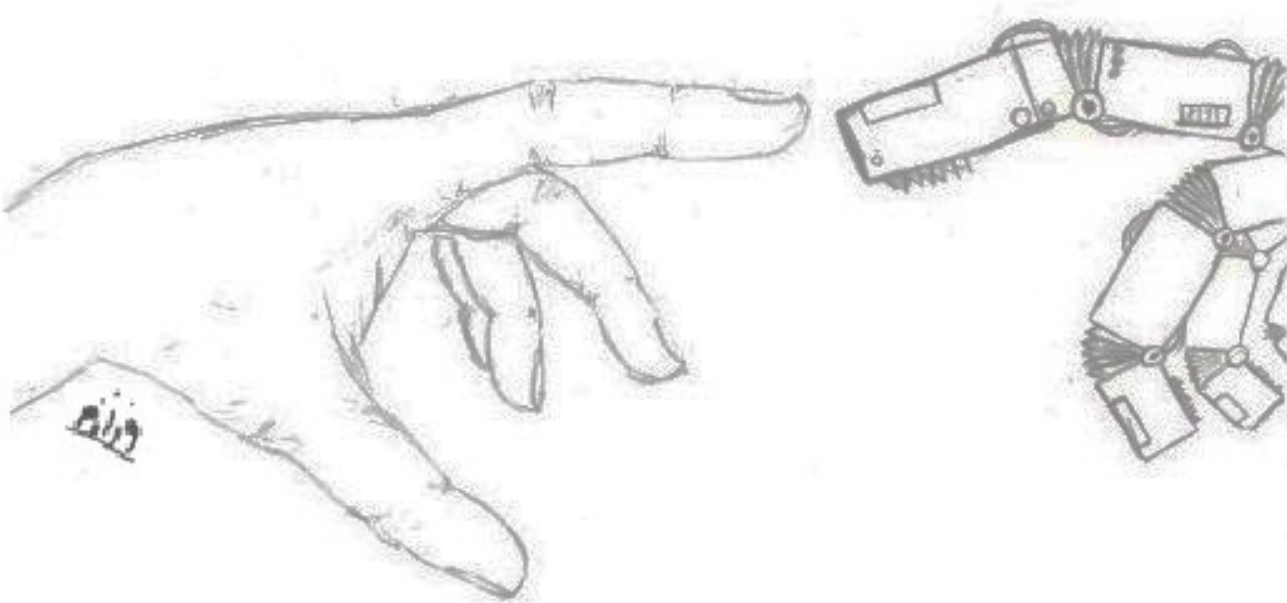

Ongoing Papers

Conferences	Venue	Dead line	Conference date	Paper's subject
ISME 2013	K. N. Toosi University of Technology, Iran	20th November 2012	5th to 7th May 2013	Maximum singularity-free workspace of Gough-Stewart platform
ICEE 2013	Ferdowsi University of Mashhad, Iran	1st December 2012	14th to 16th May 2013	Maximum singularity-free circle (MSFC) in the workspace of Gough-Stewart platform
ISRM 2013				MSFC of 3-DoF PMs using Interval Analysis
Multi-Body Dynamics 2013	Zagreb, Croatia	30th November 2012	1st to 4th July 2013	MSFC of PMs using geometrical constructive approach
AIM 2013	Wollongong, Australia	20th Jaunary 2013	9th to 12th July 2013	MSFC in Wrench-Feasible Workspace (WFW) of Cable-driven robots

Ongoing Papers

Journals	Paper's subject
MMT	6-DoF Gough-Stewart platform MSFC
Robotics and Automation IEEE	On the maximal singularity-free workspace of planar PMs
	MSFC in WFW of Cable-driven robots

Schedule

Activity	1	2	3	4	5	6	7	8	9	10
Literature studies	*	*	*	*						
Optimization Approaches		*	*	*						
Interval Analysis				*	*	*				
INTLAB				*	*	*				
IntPakx					*					
ALIAS						*	*			
First paper							*			
Other Approaches								*	*	*
Second paper										*

Schedule

Activity	11	12	13	14	15	16	17	18
Other robots	*	*						
Third paper			*					
Geometry					*	*		
Fourth paper						*		
Preparing thesis						*	*	
Defending								*

Thanks to ...

- Saman Esfehani
- Fateme Ansari
- Sarvenaz Chaee Bakhsh
- Behnam Mashhadi

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I ♥ Masoule

Rostam Abad