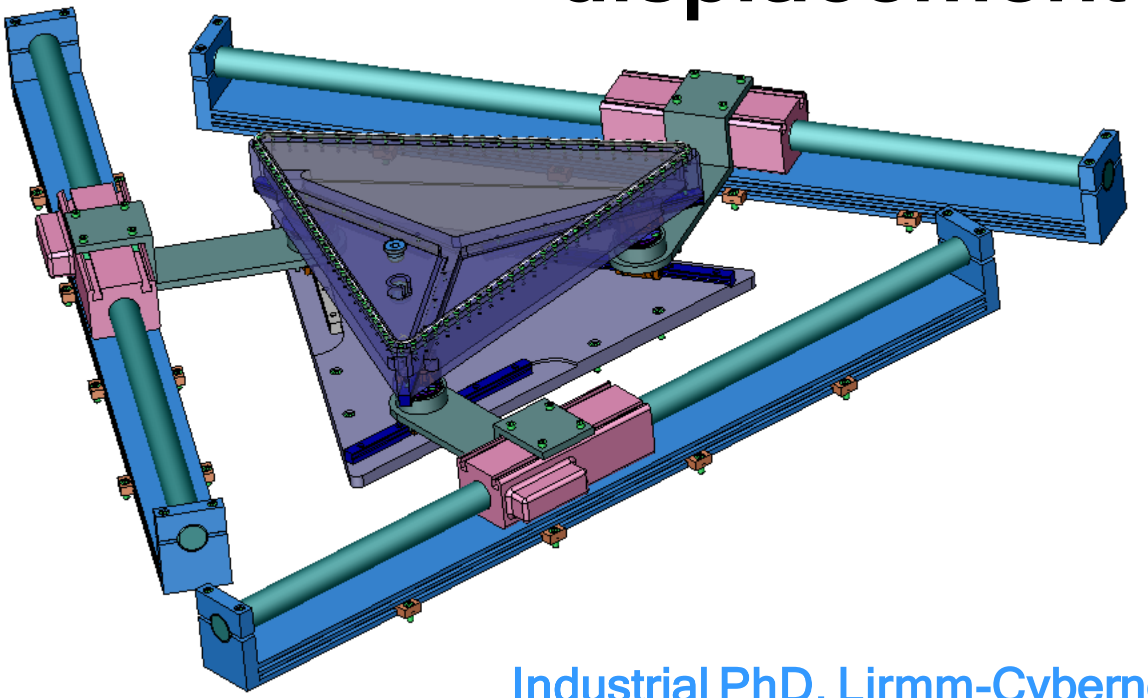
PRP planar parallel mechanism in configurations improving displacement resolution



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Synopsis of the presentation

1. Introduction and environment of the project
2. Parallel mechanisms
3. Modelization and chosen solutions
4. The machine and its realization
5. Conclusions and future work

1. Introduction (1/2)

Synopsis

1. Introduction

2. Parallel machines

3. Modelization

4. The machine

5. Conclusions and future works

- Industrial PhD between a company : Cybernétix Microélectronique and a laboratory : Lirmm, Robotics (www.cybernetix.fr, www.lirmm.fr).
- First step for both Cybernétix and Lirmm into the area of high precision positioning.
- Project : fast, and high resolution $xy\theta_z$ stage : about 10 nanometers for demanding innovative applications.

1. Introduction (2/2)

Synopsis

1. Introduction

2. Parallel machines

3. Modelization

4. The machine

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- Description of needs and requirements :
  - **Working area** : in plane, corresponding to a disc of diameter $\phi\, 300mm$ (12'').
  - **Resolution** : as good as possible, a few nanometers ($\sim 10nm$) would be acceptable.
  - **Speed** : relatively fast mechanism, positioning time less than $1s$ for a $30mm$ step.
  - **Moving mass** : $50kg$ that represent the top of the macro-stage + micro stage + top traveling plate.

2. Parallel machines - Generalities (1/3)

Synopsis

1. Introduction

2. Parallel machines
- Generalities
- Singularities
- Planar robots

3. Modelization

4. The machine

5. Conclusions and future works

- 2 major kinds of mechanisms in robotics : classical manipulators as serial robots, with some anthropomorphic characteristics.
  - Ratio moving load / robot weight low (about 0.15).
  - Poor accuracy : positioning accuracy, repeatability.
  - Not really able to work for small size scales because friction > actuation.

Serial robot

Synopsis

1. Introduction

2. Parallel machines
- Generalities
- Singularities
- Planar robots

3. Modelization

4. The machine

5. Conclusions and future works

2. Parallel machines - Generalities (2/3)

- Emerging kind of mechanical architecture, the parallel structure :
  - *'Mechanism in closed kinematic loop whose output element (traveling plate) is linked to the basement with several independent kinematic chains'.*
- Advantages :
  - Better load distribution (on several kinematic chains).
  - Good stiffness of components (reduced elements strain).
  - Decrease of the moving mass.
  - Use of linear actuators in parallel avoid the accumulation of mistakes due to serial architecture.

Synopsis

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Parallel structure

Synopsis

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- Generalities
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2. Parallel machines - Generalities (3/3)

- Advantages :
  - Interesting dynamic performances : speed, very high accelerations (up to 80g, often 10g).
  - Possibility to carry an important moving mass : ratio moving mass / robot mass = 10).

Synopsis

1. Introduction

2. Parallel machines
- Generalities
- Singularities
- Planar robots

3. Modelization

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2. Parallel machines - Singularities (1/3)

- In robotics, *singularities* are particular positions of the end-effector in which the behavior of the manipulator is highly damaged.
- In general, these positions are avoided…
- Idea : use this drawback as an advantage under certain conditions in an area near the singular positions.
- 2 major kinds of singularities :
  - Parallel.
  - Serial.

Synopsis

1. Introduction

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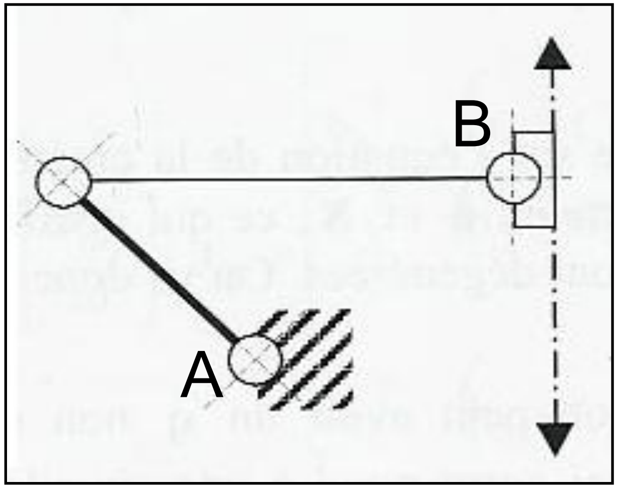
2. Parallel machines - Singularities (2/3)

- Parallel singularity :
  - To overcome a small effort on the end-effector (B), an infinite torque is required for the actuator (A).
  - A small displacement of the actuator (A) produces 0 displacement of the end-effector (B).



Parallel singularity

2. Parallel machines - Singularities (3/3)

Synopsis

1. Introduction

2. Parallel machines
- Generalities
- Singularities
- Planar robots

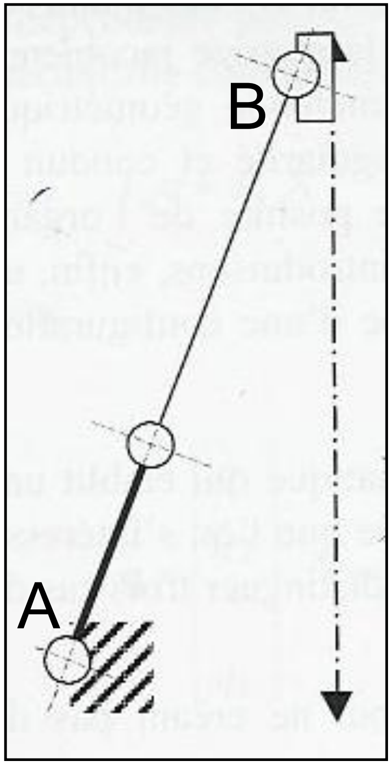
3. Modelization

4. The machine

5. Conclusions and future works

- Serial singularity :
  - An effort on the end-effector (B) produces 0 torque for the actuator (A).
  - A small displacement of the actuator (A) produces a smaller displacement of the end-effector (B)

Important reduction ratio



Serial singularity

Synopsis

1. Introduction

2. Parallel machines
- Generalities
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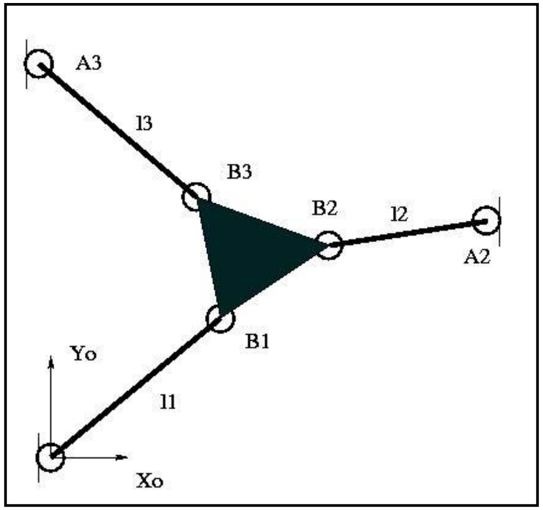
2. Parallel machines – Planar robots

- Traveling plate linked to the basement by 3 kinematic chains.
- 3 degrees of freedom :
  - 1 rotation around the normal to plane.
  - 2 translations.



Planar parallel robot

3. Modelization – Geometry (1/2)

Synopsis

1. Introduction

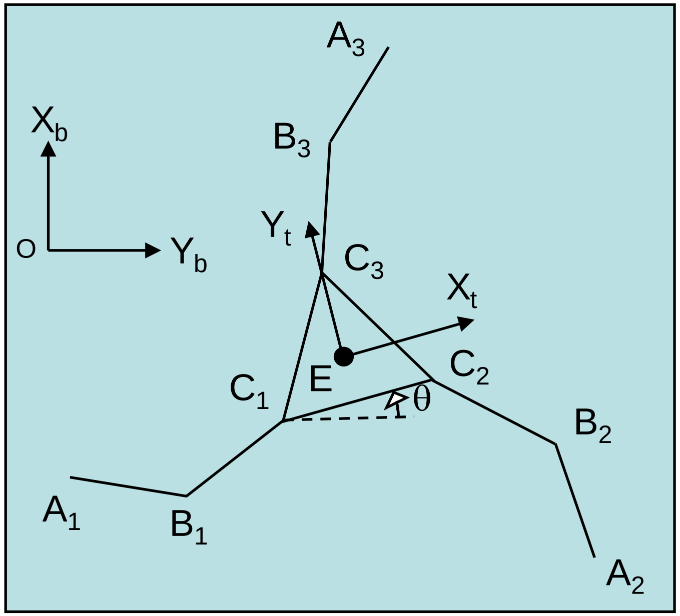
2. Parallel machines

3. Modelization
- Geometry
- Inverse models
- Simulations

4. The machine

5. Conclusions and future works

- 7 different kinds of kinematic chains to build planar parallel robots : combination of prismatic (P) and rotoïde joints (R), like RPR, RRR, …



General class of planar parallel manipulators

Synopsis

1. Introduction

2. Parallel machines

3. Modelization
- Geometry
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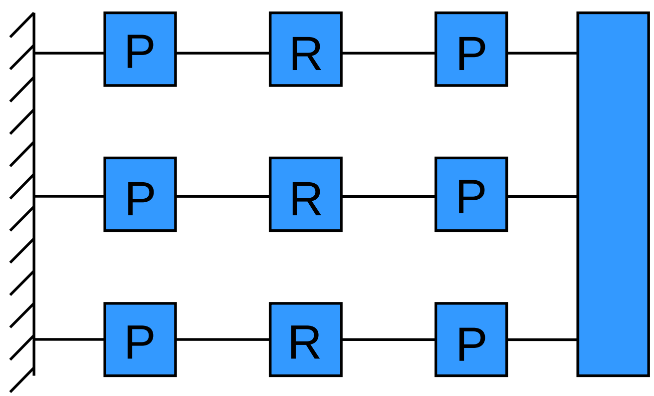
4. The machine

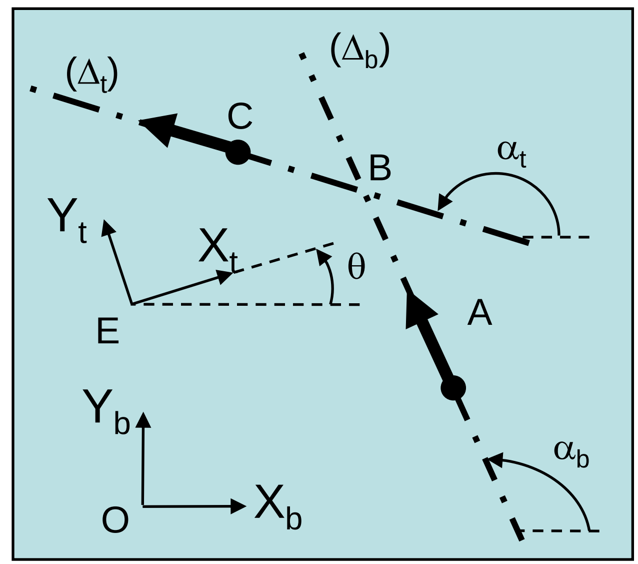
5. Conclusions and future works

3. Modelization – Geometry (2/2)

- Choice PRP :
  - Reduced accuracy problems : no bending parts.
  - Good behavior regarding to inertia considerations.



Structural graph of PRP mechanism



One chain of PRP mechanism

Synopsis

1. Introduction

2. Parallel machines

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4. The machine

5. Conclusions and future works

3. Modelization – Inverse models

- <u>**Inverse positions**</u> : position parameters of the actuators $\boldsymbol{q}$ for a set of position and orientation of the end-effector $(x,y,\theta_z) \Rightarrow q = f(x, y, \theta_z)$.
- <u>**Inverse velocities**</u> : velocity parameters $\dot{q}$ of the actuators for a set of velocities of the end-effector $\dot{X} = \left(\dot{x}, \dot{y}, \dot{\theta}_z\right) \Rightarrow \dot{q} = J\,\dot{X}$.
- <u>**Property of the PRP mechanism**</u> : if the directions of 1st and 2nd prismatic joints are equally spaced at $120°$ $\Rightarrow$ possibility to move with a constant orientation along the xy plane.

Synopsis

1. Introduction

2. Parallel machines

3. Modelization
- Geometry
- Inverse models
- Simulations

4. The machine

5. Conclusions and future works

3. Modelization – Simulations (1/4)

- **Purpose** : find the best configuration for PRP mechanism with equal spacing in directions of prismatic joints to improve resolution.
- 4 theorical shapes $\Rightarrow$ 2 kept for simulations :
  - Triangle-triangle.
  - Triangle-star.
- Data for the initialization of simulations :
  - Actuator stroke : 800 mm.
  - Reachable workspace : disc of ϕ 300 mm.
  - Motion : along x and y axis, for θ_z limited to $\pm 5°$.

Synopsis

1. Introduction

2. Parallel machines

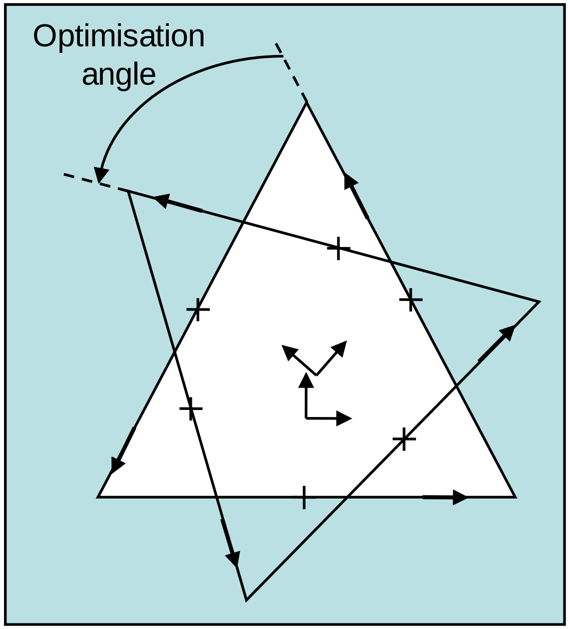
3. Modelization
- Geometry
- Inverse models
- Simulations

4. The machine

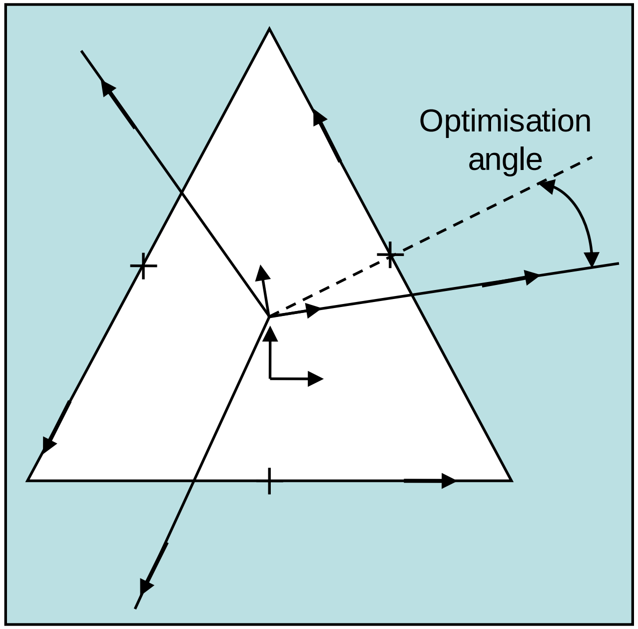
5. Conclusions and future works

3. Modelization - Simulations (2/4)

- Description of T-T and T-S PRP mechanisms



Triangle-triangle mechanism



Triangle-star mechanism

Synopsis

1. Introduction

2. Parallel machines

3. Modelization
- Geometry
- Inverse models
- Simulations

4. The machine

5. Conclusions and future works

3. Modelization – Simulations (3/4)

- Criteria of choice : best use of actuator stroke

  $\Rightarrow$ increase of resolution while :
  - Achieving the reachable workspace (disc $\phi\, 300\, mm$).
  - Keeping a good conditioning for the system (<2).
- Matlab® computing $\Rightarrow$ best optimization angle :
  - 20 ° for triangle-triangle mechanism.
  - 40 ° for triangle-star mechanism.

  $\Rightarrow$ Same position for both mechanisms
- Necessity to search into these 2 kinds for the best balanced mechanism.

Synopsis

1. Introduction

2. Parallel machines

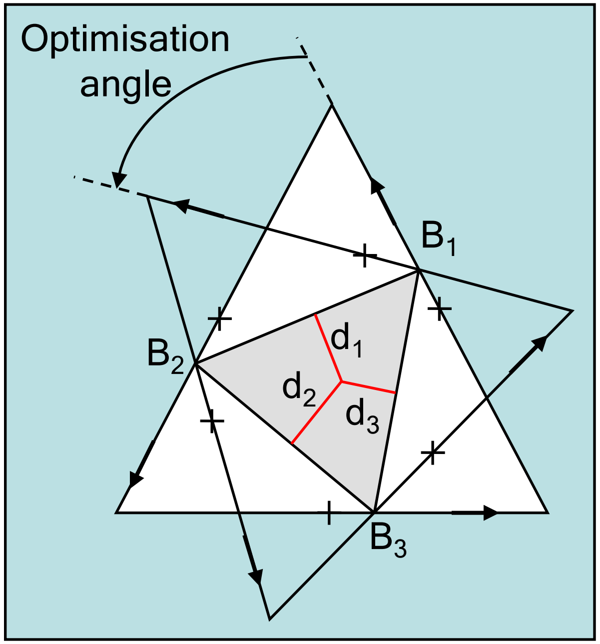
3. Modelization
- Geometry
- Inverse models
- Simulations

4. The machine

5. Conclusions and future works

3. Modelization – Simulations (4/4)

- Criteria of choice for balance :
  - Minimum surface of triangle $B_1B_2B_3$.
  - Minimum distance d_1, d_2, d_3.



Example of description of the criteria for the T-T mechanism

<u>Final choice :</u>

- Triangle-star (best balance) mechanism.
- Optimization angle of 40 °.
- Resolution improvement of 1.73.

Synopsis

4. The machine – Global architecture

1. Introduction

2. Parallel machines

3. Modelization

4. The machine
- Global architecture
- Macro

5. Conclusions and future works

- Macro / Micro architecture.
- Use of 2 planar parallel mechanisms : one for the macro-stage (PRP) and one for the micro-stage (probably RRR) both in quasi-singular position.
- Direct measurement.
- Heavy moving mass : low thermal inertia.
- First intent $\Rightarrow$ workspace disc of $\phi\, 300\,mm$.
- Planarization of realization of a prototype $\Rightarrow$ reduction to disc of $\phi\, 70\,mm$ (cost related).

Synopsis

1. Introduction

2. Parallel machines

3. Modelization

4. The machine
- Global architecture
- Macro-stage

5. Conclusions and future works

4. The machine – Macro-stage

⇒ Macro-stage has been designed using Solidworks2001+ ®

- Traveling plate is sunken and filled with water for thermal inertia and mass considerations.

5. Conclusions and future work

Synopsis

1. Introduction

2. Parallel machines

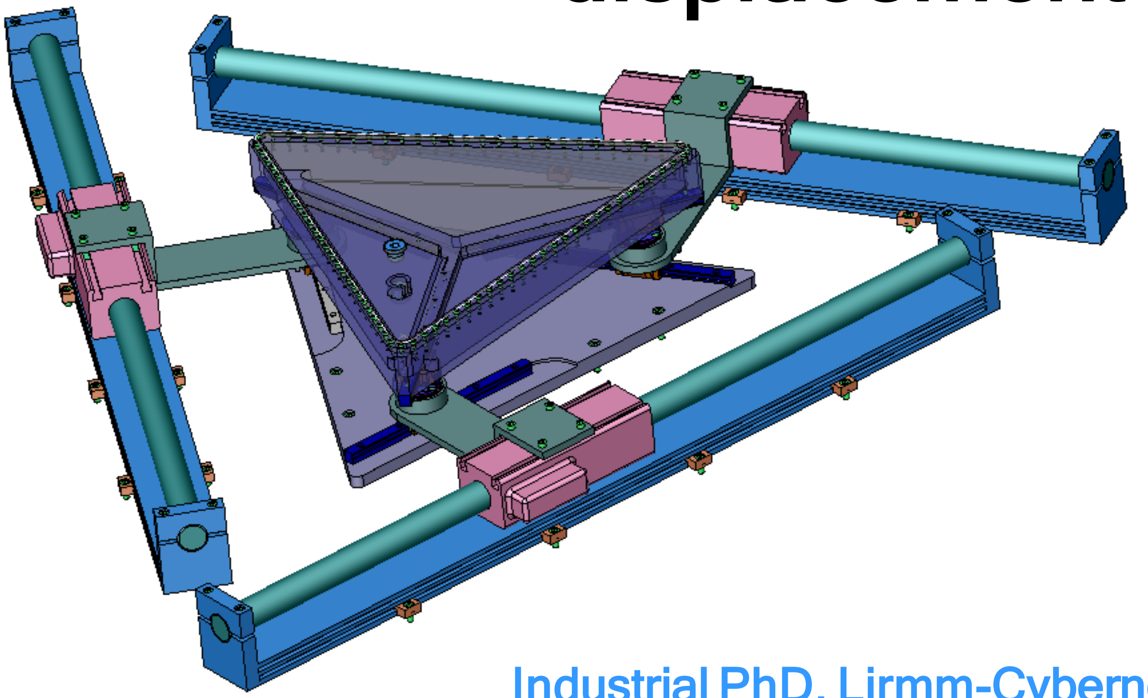
3. Modelization

4. The machine

5. Conclusions and future works

- PRP planar parallel mechanism in configuration improving displacement resolution.
- Application of this principle in the design of the Macro-stage of a prototype.
- Machining of the parts and purchase of the standard parts are in process.
- Soon : assembly and control of this Macro-stage.
- Later : detailed design and realization of the Micro-stage (probably RRR quasi singular).

PRP planar parallel mechanism in configurations improving displacement resolution



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