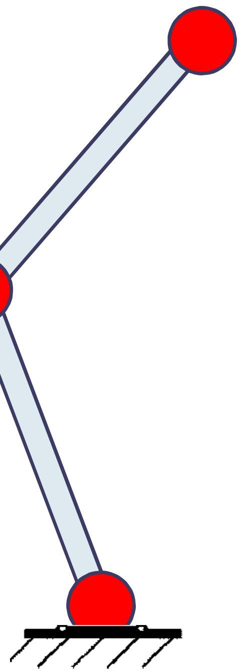
Partie 2

Parallel robotics

Parallel vs Serial robots

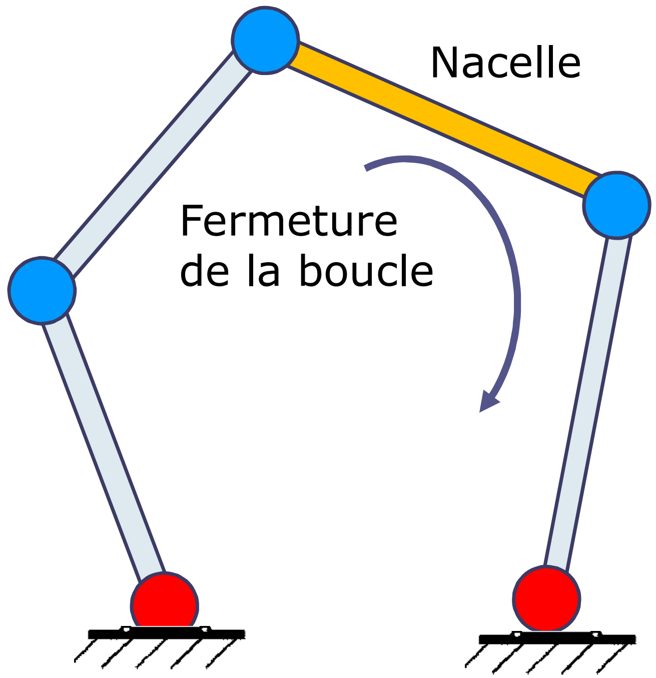
Serial robots

With **actuated segments in series**



Parallel robots

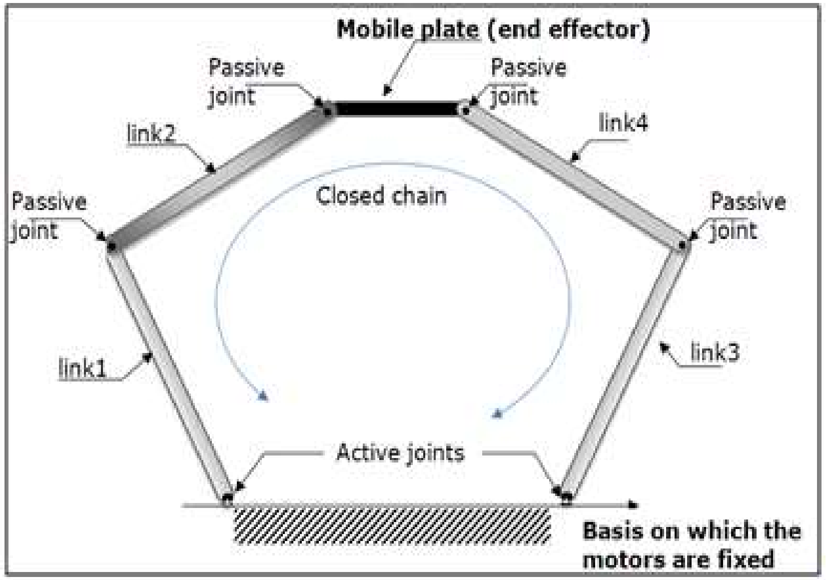
- ✓ Robots with closed kinematic chains
- ✓ All the motors are on the basis



Leightweight, fast and stiff

1. All the kinematic **chains** from the basis to the mobile parts are **closed** to the basis.
2. All the **motors are on the basis** and no one is on the structure. The **intermediate joints** in the structure are all **passive**.

Mitsubishi RP 1AH

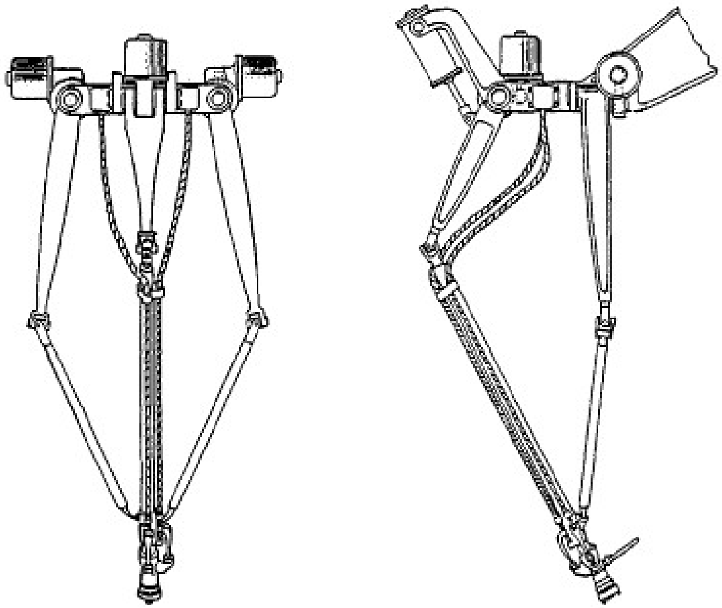


Close the chain and let us talk about parallel kinematics !

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Since When?

The oldest «known» is
Pollard robot (Pollard 1938) invented by
Mr Pollard



[L. E. Rey, Environnement pour la conception de commandes de robots, PhD thesis, EPFL,1997

Parallel link to remote an actuator and make the link stiffer

The Most known

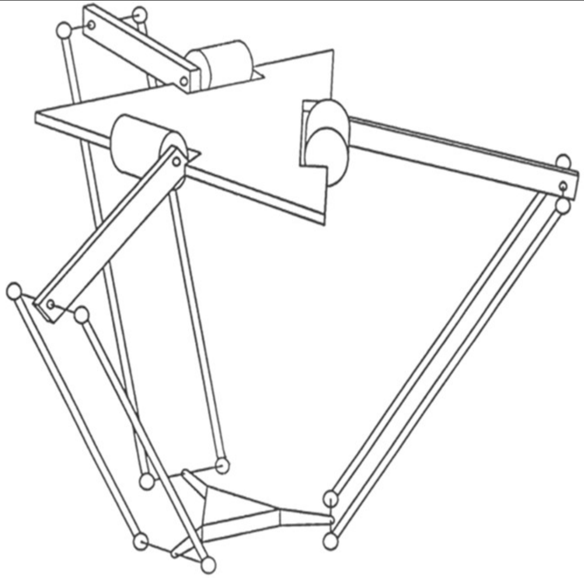
The flight simulator

The Gough Stewart platform

7 years : from the idea to the customer!

1985: Patented by R. Clavel (EPFL)

Principle

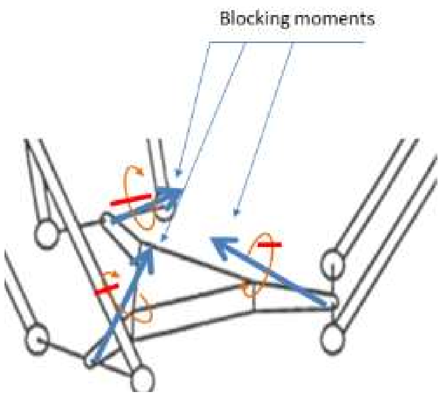


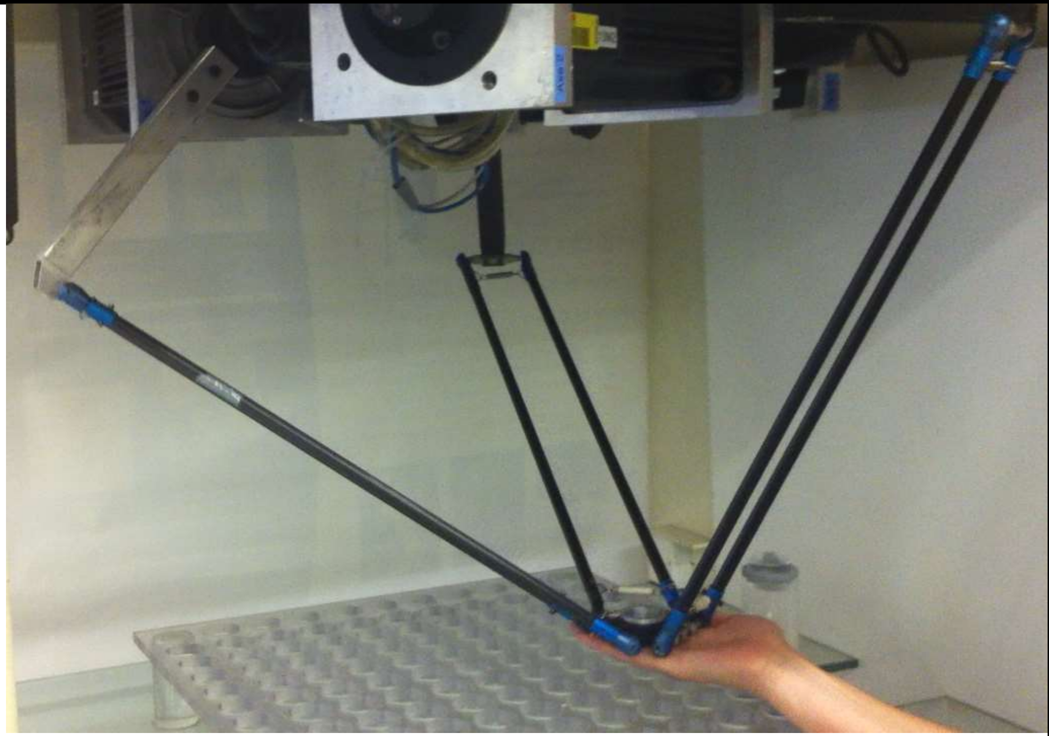
1988 – The patent is Sold to the Swiss company Demaurex SA (currently **Bosch Packaging Technology** Unit, Romanel).
1992– The first customer was Nestlé.

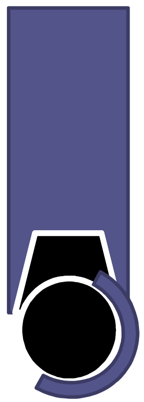
> Has been the **precursor** for the market of parallel robotics.

More than **100 companies** have adopted this kinematics since **2007** when the patent was in the public domain

The robot "Delta"







Another realization

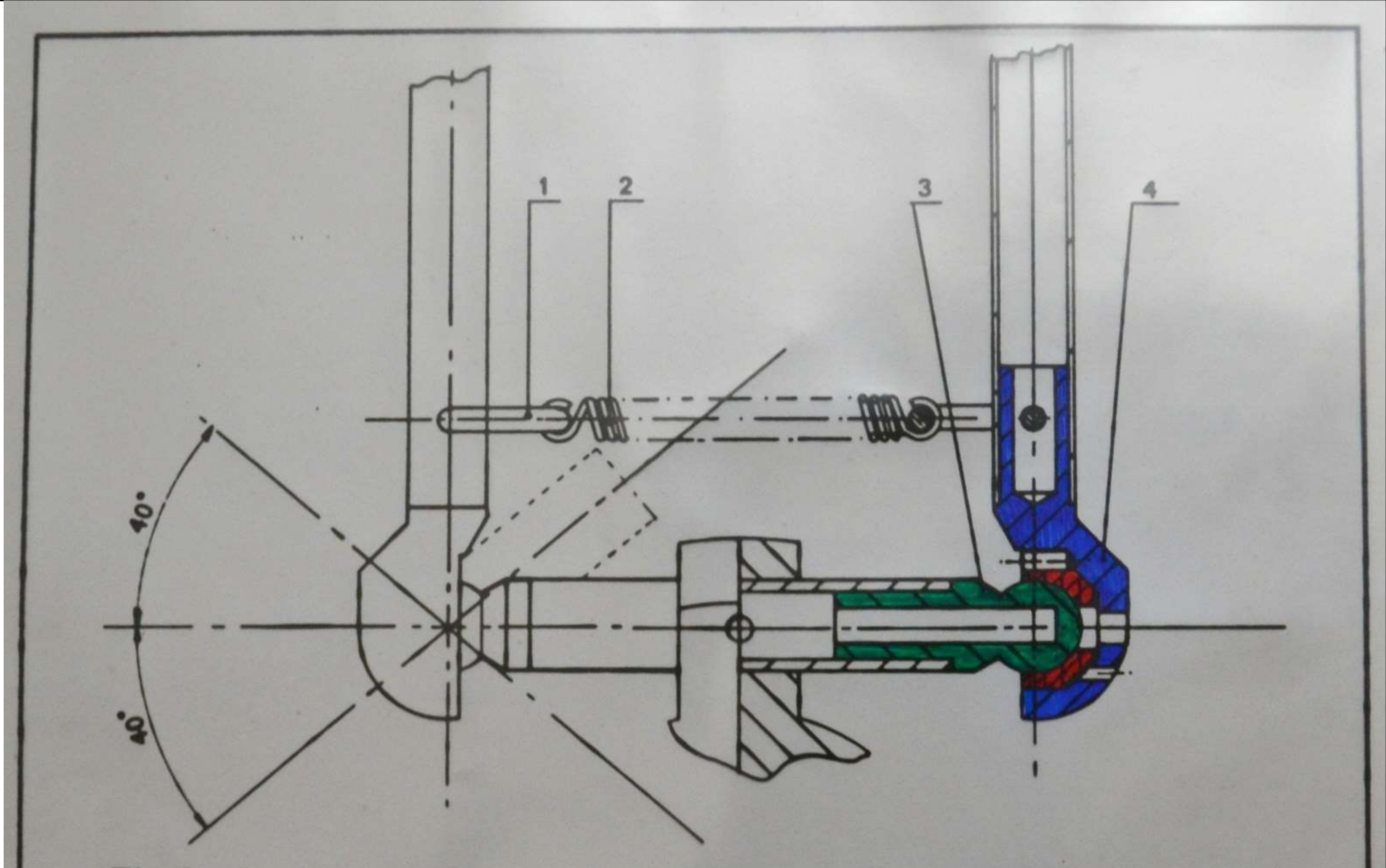
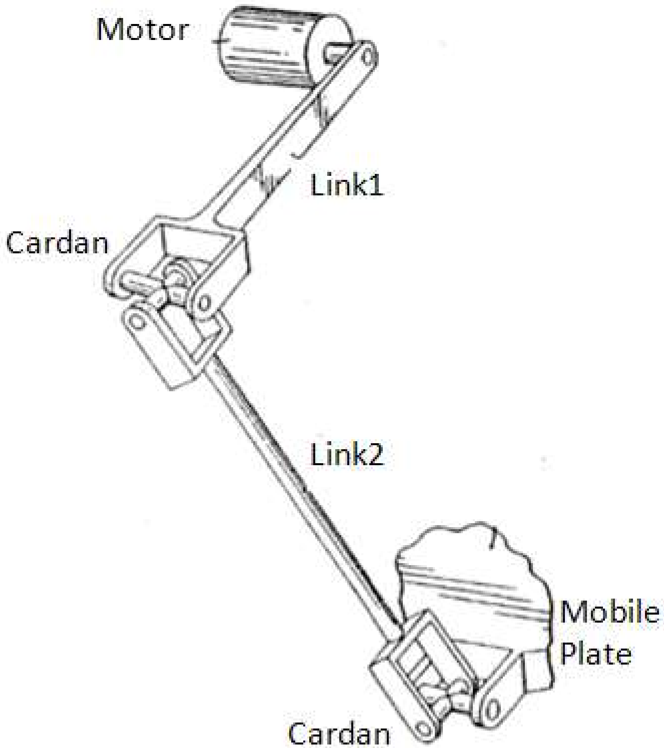
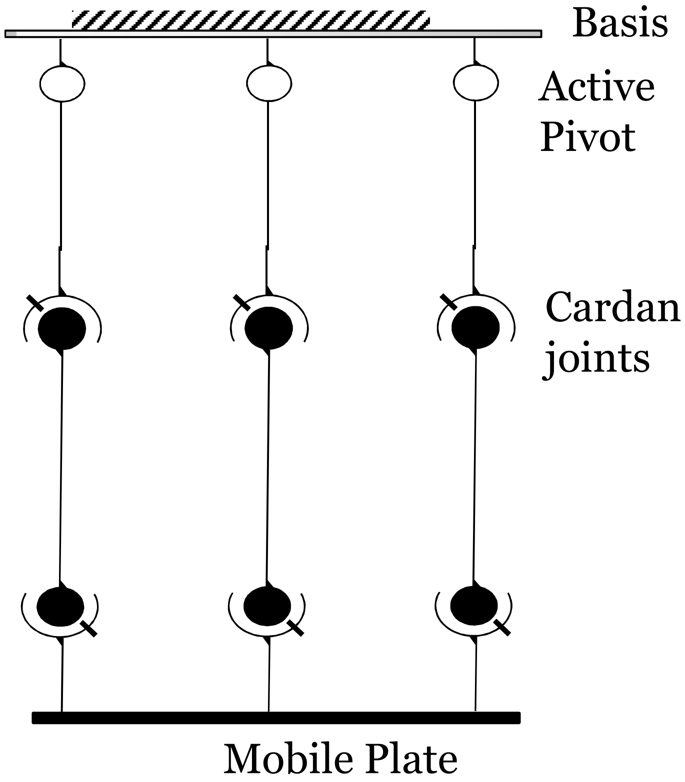


Fig.5. Detail of the construction of the arm - parallelogram joint.

The simplest variant: with cardans at the passive joints



Representation of one kinematic chain



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Mobilité de robots parallèles

La mobilité d'un robot est une image de son nombre de **degrés de liberté.**

C'est l'ensemble des mobilités des éléments constituants le robots en considérant bien sûre les contraintes cinématiques de la structure.

Dans le cas d'un robot sériel, la mobilité est égale au **nombre de moteurs.**

[!] c'est la dimension de l'espace articulaire.

Dans le cas d'un robot parallèle, Il existe des formule permettant de calculer la mobilité

- **Formule de Grübler.**
- **Formule des boucles.**

Formule de Grübler

By considering a kinematic structure composed by **n solid elements**, the degrees of freedom (called DOF or Mobility MO) of this set of elements before any assembly is obviously equal to $\boldsymbol{MO = 6.n}$ (each element has 6 spatial DOF). Each link between 2 elements reduces the total mobility by a value corresponding to the number of the generalized forces (NGF) in the considered link. With **k joints**, the mobility is computed as follows:

$$MO = 6n - \sum_{i=1}^{k} NGF_i$$

The number of the generalized forces (NGFi) involved in a considered joint is a complementary to 6 of the number of the degrees of freedom (MOi). We then obtain:

$NGF_i = 6 - MO_i$

And hence: $MO = 6n - 6k + \sum_{i=1}^{k} MO_i$

That gives: $MO = 6(n - k) + \sum_{i=1}^{k} MO_i$

Since one element of the structure is fixed on the frame, its 6 DOF must be differentiated from the total mobility number MO. We obtain:

$$\boldsymbol{MO = 6(n - k - 1) + \sum_{i=1}^{k} MO_i}$$

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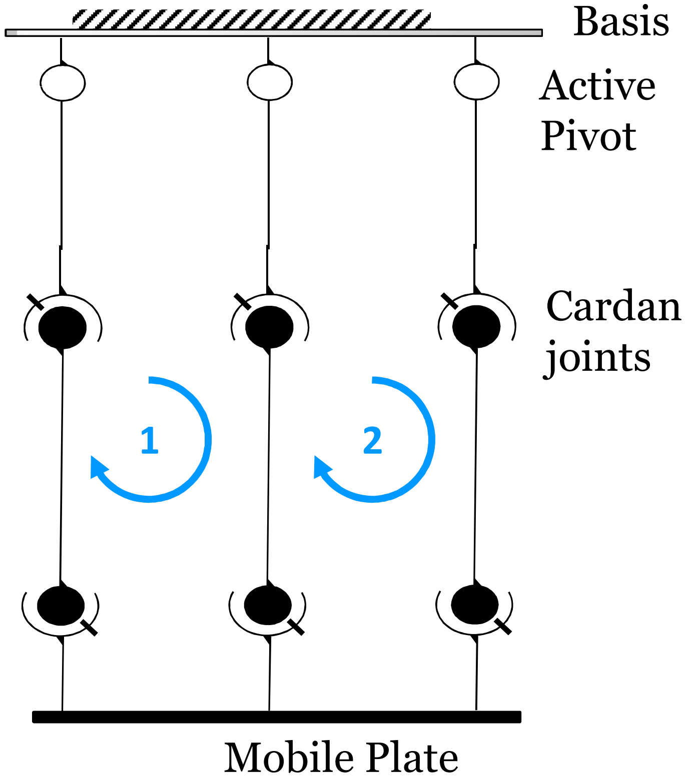
Formule des boucles

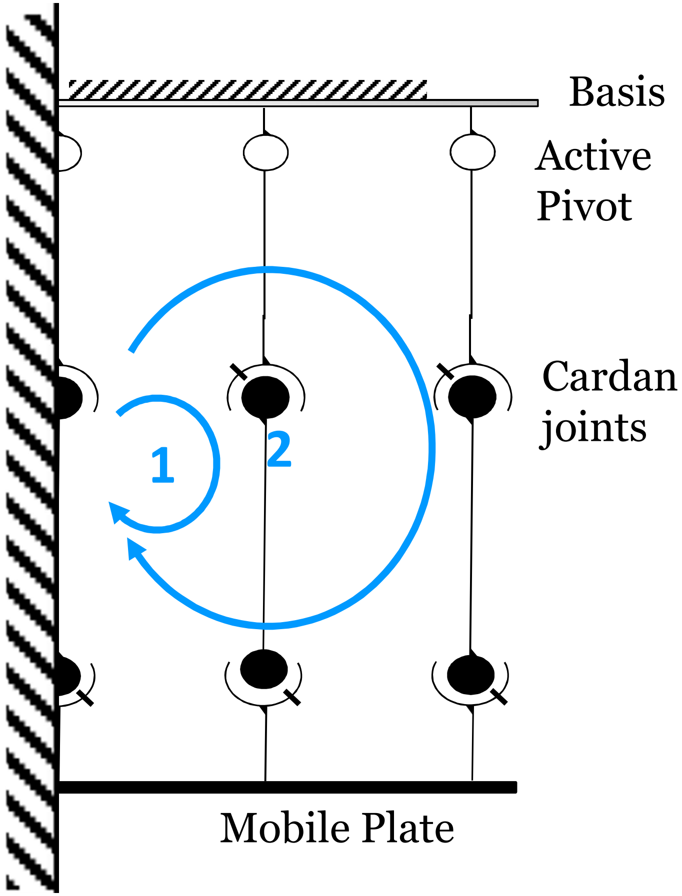
$$MO = \sum_{i=1}^{k} MO_i - 6bo$$

Comment compter les boucles?

1- Boucles disjointes



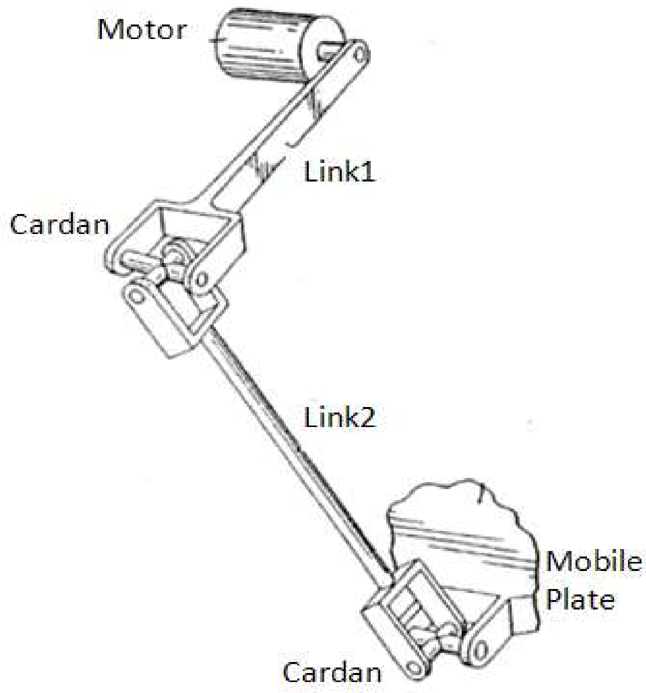
2- Boucles fermées sur la même référence



Delta with gimbals: Exercise ☺

Example 1,

- Give the Kinematic representation of a Delta with gimbals.
- Calculate its mobility.
- Conclude…



Representation of one kinematic chain of the cardan based Delta

Delta with gimbals: Calculation of the Mobility ☺

By applying the Grübler formula, we have:

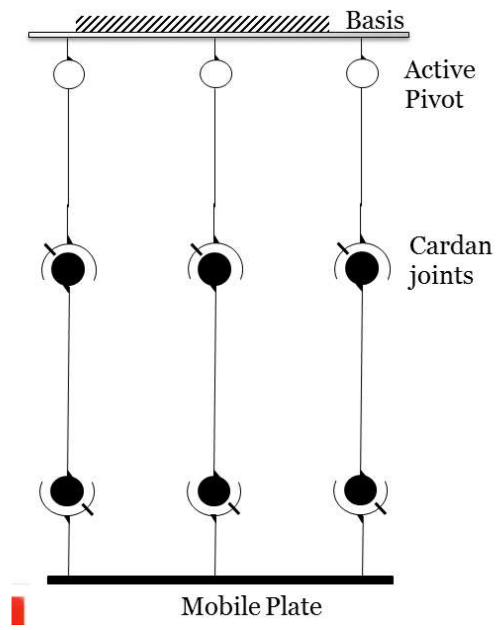
- The number of elements of the structure is **n = 8** (1+1+3.2) {1 basis + 1 mobile plate + 3 arms + 3 forearms}.

- The number of joints **k =9** {(1 pivot + 2 cardans) X 3 identical links}.

- The mobility of the pivot is equal to **1**. The mobility of each cardan is equal to **2**. The total mobility of this Delta is then computed as follows:

$$\boldsymbol{MO = 6.(8 - 9 - 1) + \{1 + 2 + 2\}.3 = -12 + 15 = 3}$$

$$\boldsymbol{MO = 6(n - k - 1) + \sum_{i=1}^{k} MO_i}$$



Delta with gimbals ☺

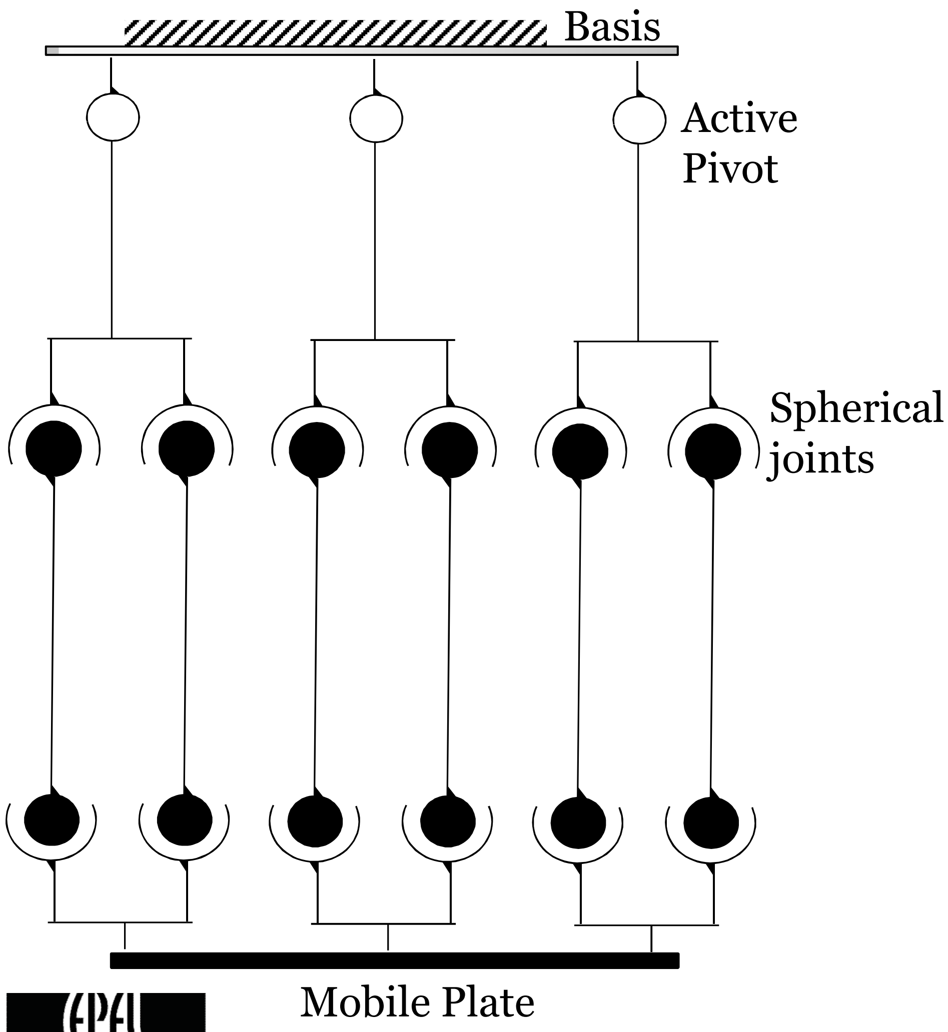
Using gimbals instead of a parallel bars and spherical joints

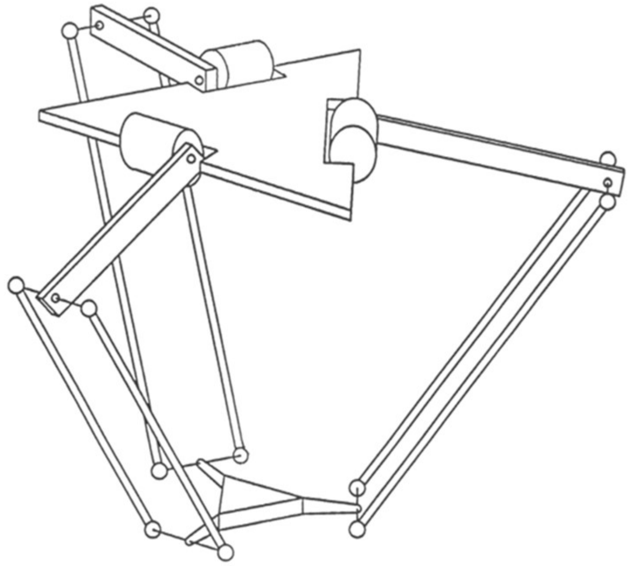
Never do it….

- The structure is not enough stiff
- Not easy to find gimbals with reduced play.
- The play will reduce the proper mechanical frequency

Never say never ….

The most common realization





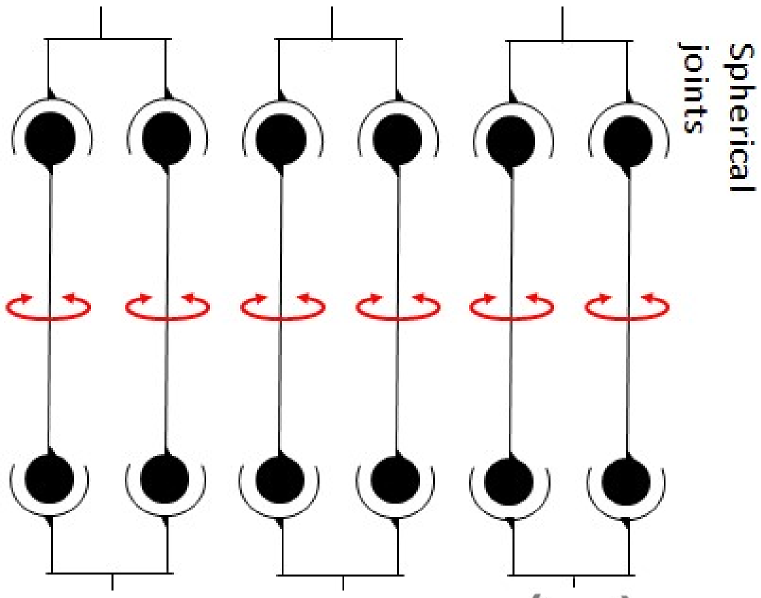
- **n = 11** (1+1+3.3) {1 basis + 1 mobile plate + 3 arms + 6 bars}.
- **k =15** {(1 pivot + 4 spherical joints) X 3 identical links}.

$$\boldsymbol{MO} = \mathbf{6.(11 - 15 - 1) + \{1 + 4.3\}.3}$$

$$= \mathbf{-30 + 39 = 9}$$

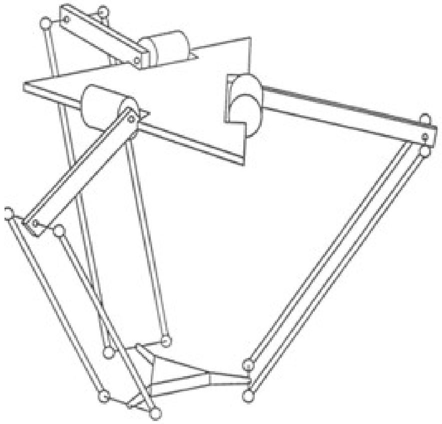
Observation

- The Delta robot as designed with the parallel bars and spherical joints has **6 supplementary mobilities**.
- These mobilities concern **internal mobilities** not affecting **the pure translation of the mobile plate**.
- They are actually related to the **rotation of each bar around its principal axis**.

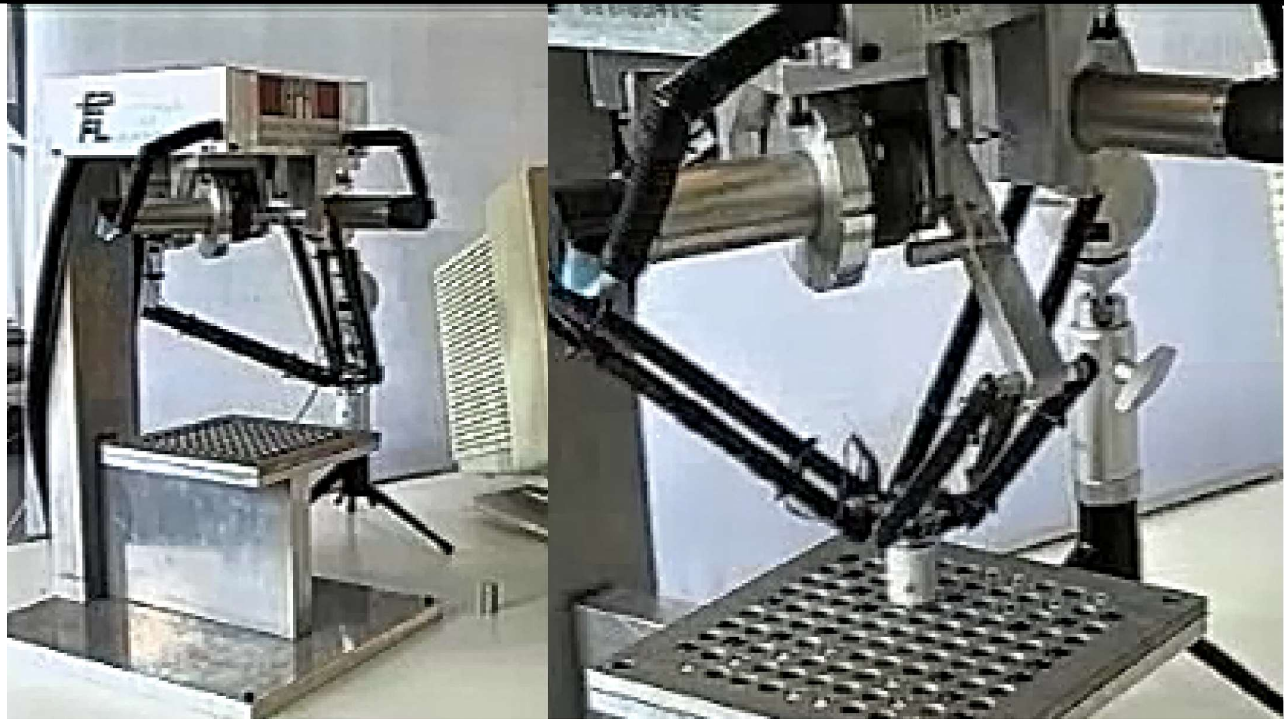


- Springs limit the internal mobility at the cost of friction
- The internal mobility does not affect the final precision of the end effector at the condition of an ideal spherical contact of the spherical joints

Simplicity of the Delta



Parallel bars



Motor + Gear Box+ Arm + Fore arms
Motor + Gear Box+ Arm + Fore arms
Motor + Gear Box+ Arm + Fore arms

+

Mobile plate

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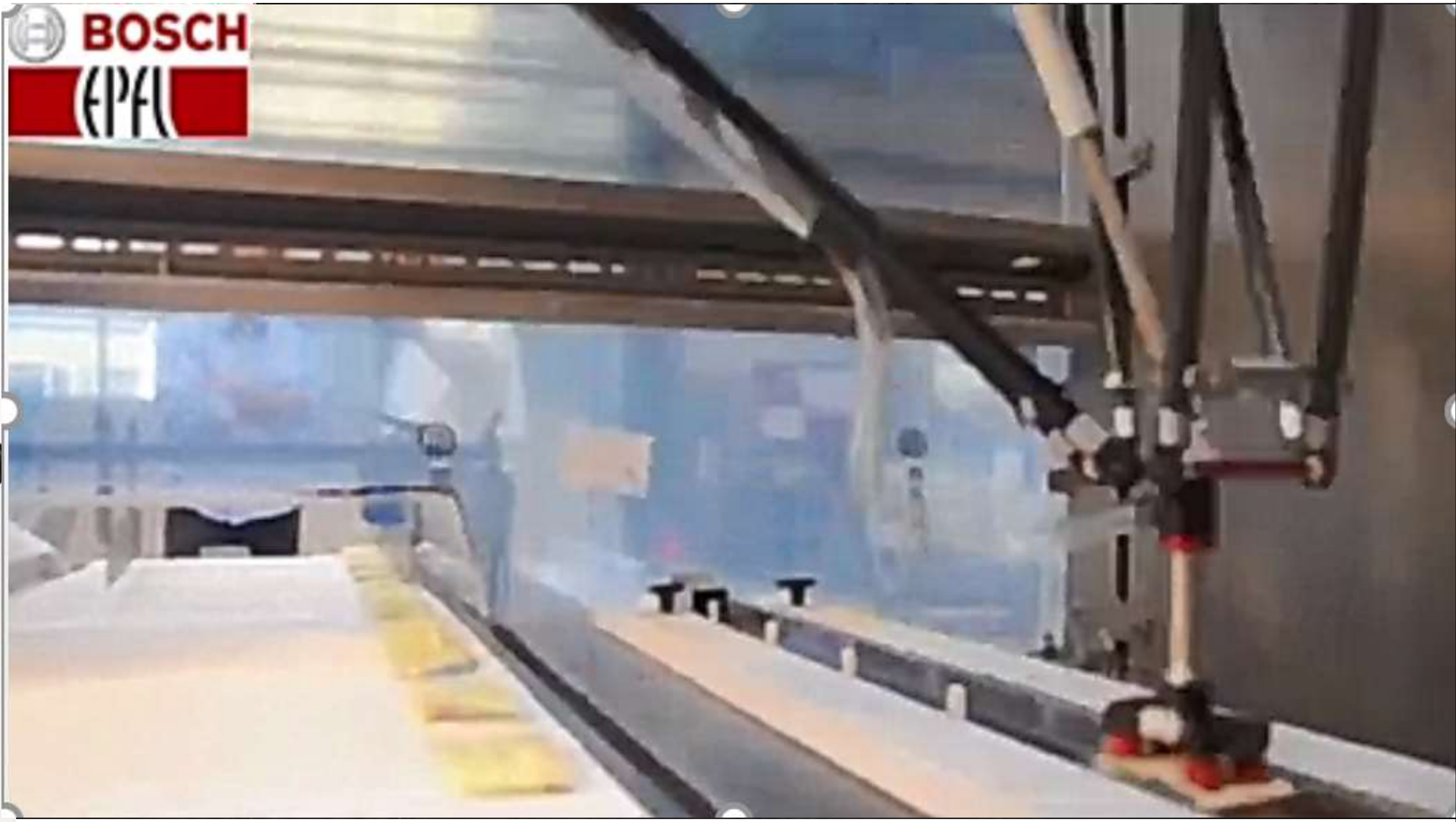
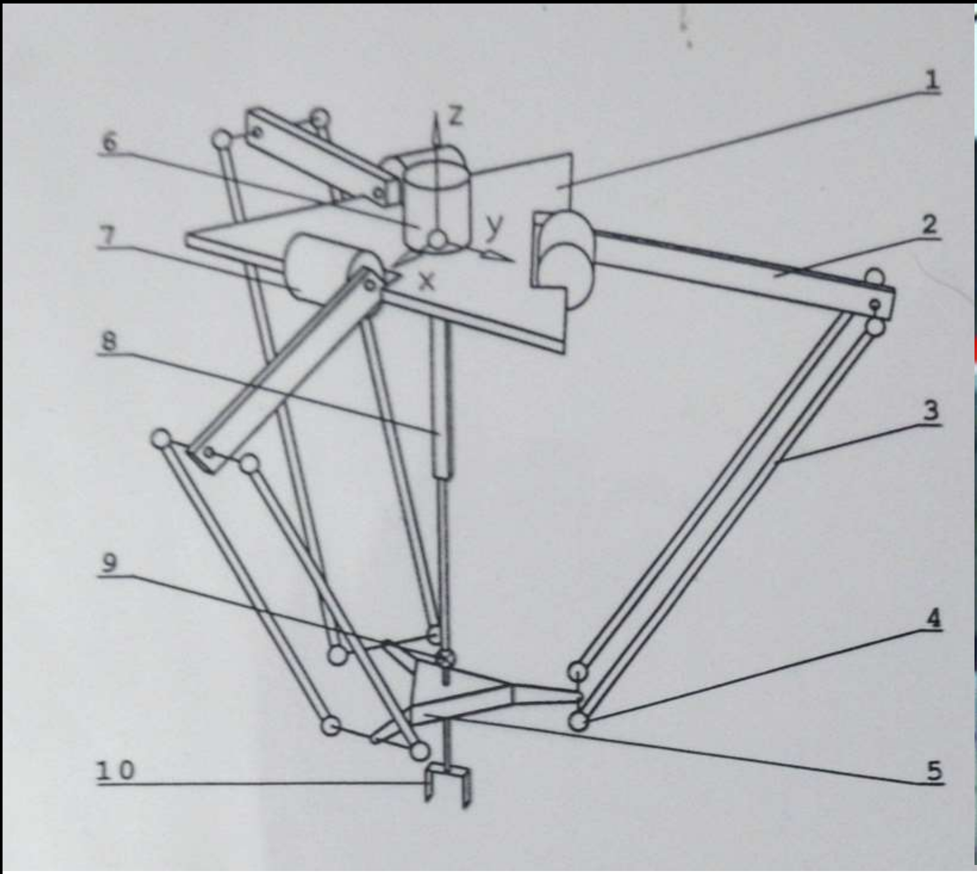
The adventure does not finish

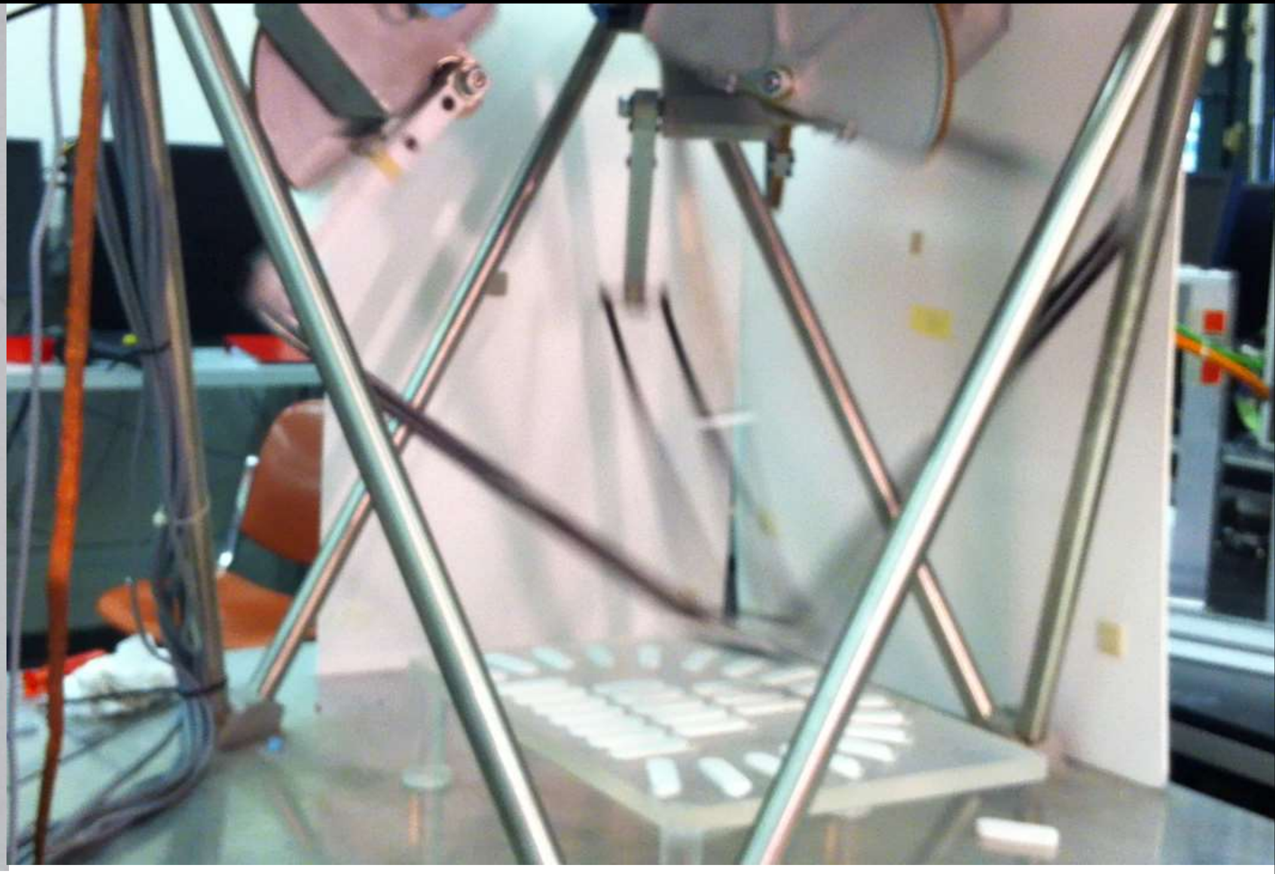
Direct Drive Actuated Delta realized for **BOSCH Packaging Technology**



[Patent 2012] **Device For Moving And Positioning An Object In Space**, Huser M., Tschudi M., Keiffer D., Teklits A., **Bouri M.**, Clavel R., Demaurex MO., Device For Moving And Positioning An Object In Space, reference WO2012152559

Some Variants of the Delta



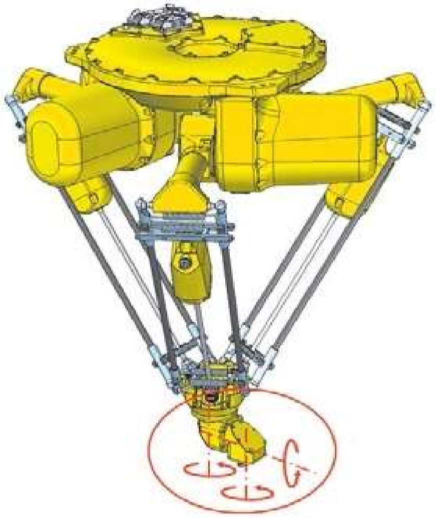


Angular Delta with **4 DOF**

Additional DOF : Serial or Parallel?

Other companies are proposing parallel robots in their catalog:

1. **Mitsubishi** that proposes the double Scara robot.
2. **ABB** (with his Delta FlexPicker).
3. **Demaurex** at Ecublens, VD/ CH
4. **Adept** that is proposing the Quattro robot
5. **Fanuc** that proposes different variants of the Delta robot.



Fanuc

ABB

Demaurex (the first manufacturer of the Delta)

Other companies are proposing parallel robots in their catalog:

Fanuc robots

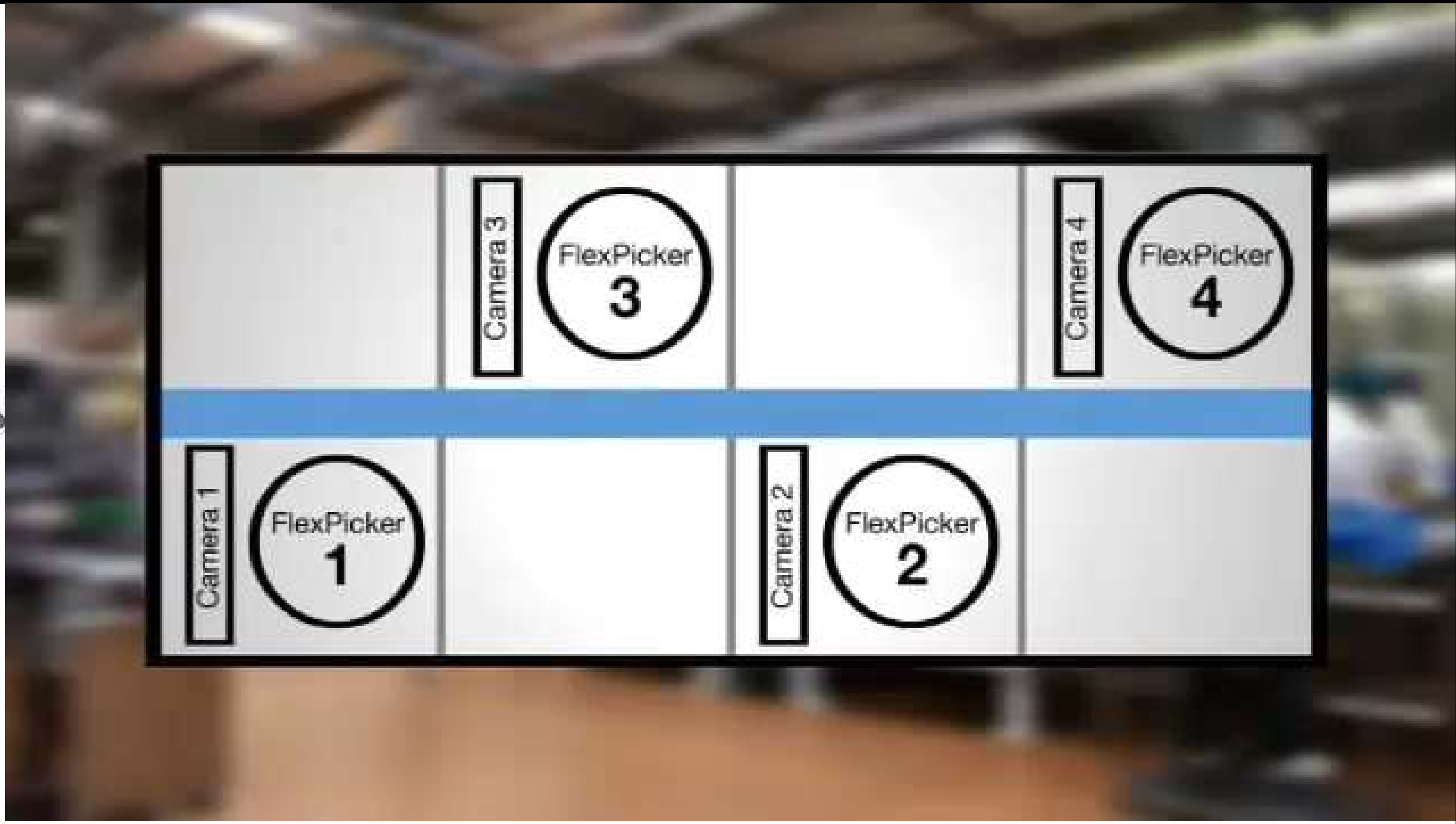
6 axes

Omron robots

IP67

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

ABB - example



4 axes – Delta robot

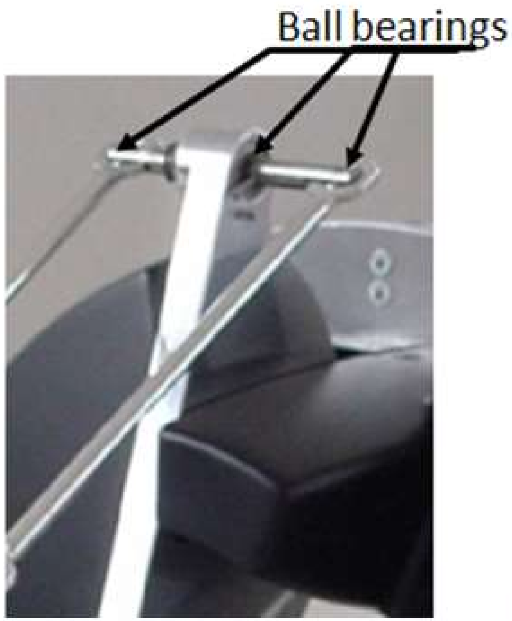
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Delta Omega: Parallel robotics for haptic feedback

How to reduce friction ?

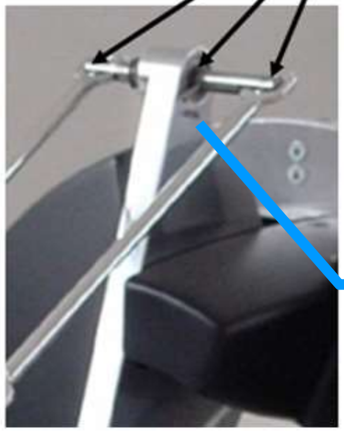
How to reduce friction while keeping big torques ?

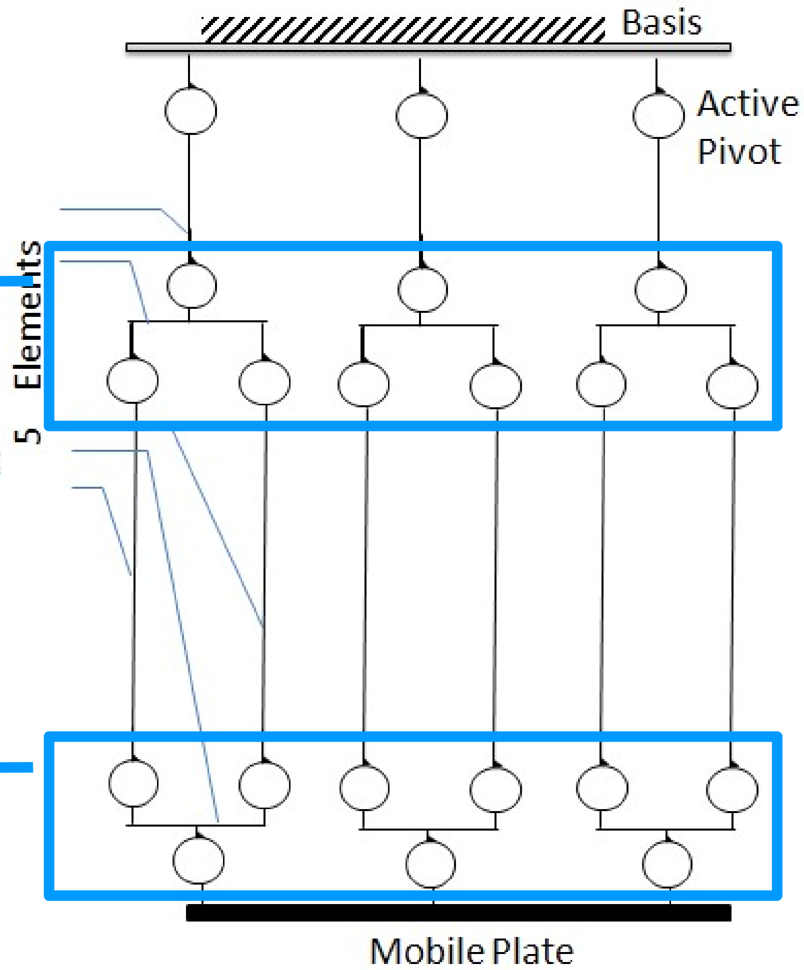
Robot Omega from Force Dimension (Nyon) for haptic feedback and tele-manipulation



[Force dimension, CH, http://www.forcedimension.com/]

What is about the mobility of the Delta Omega ?





- **n = 17** (1+1+5 X 3)

  {1 basis + 1 mobile plate + 5 elements X 3}.

- **k =21** {(1 pivot + 4 spherical joints) X 3

  identical links}.

$$\boldsymbol{MO = 6.(17 - 21 - 1) + \{21\} = -9}$$

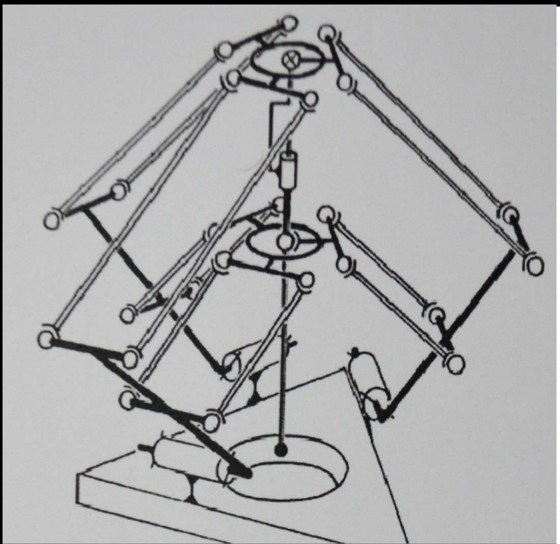
Over-constraint of order 12

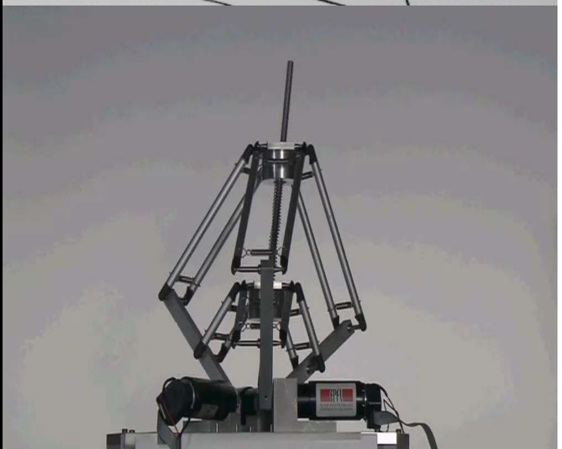
The Quattro – 4 DOFs from Omron (prev. Adept)

Parallel Robot (Delta Robot): Adept Quattro s650H

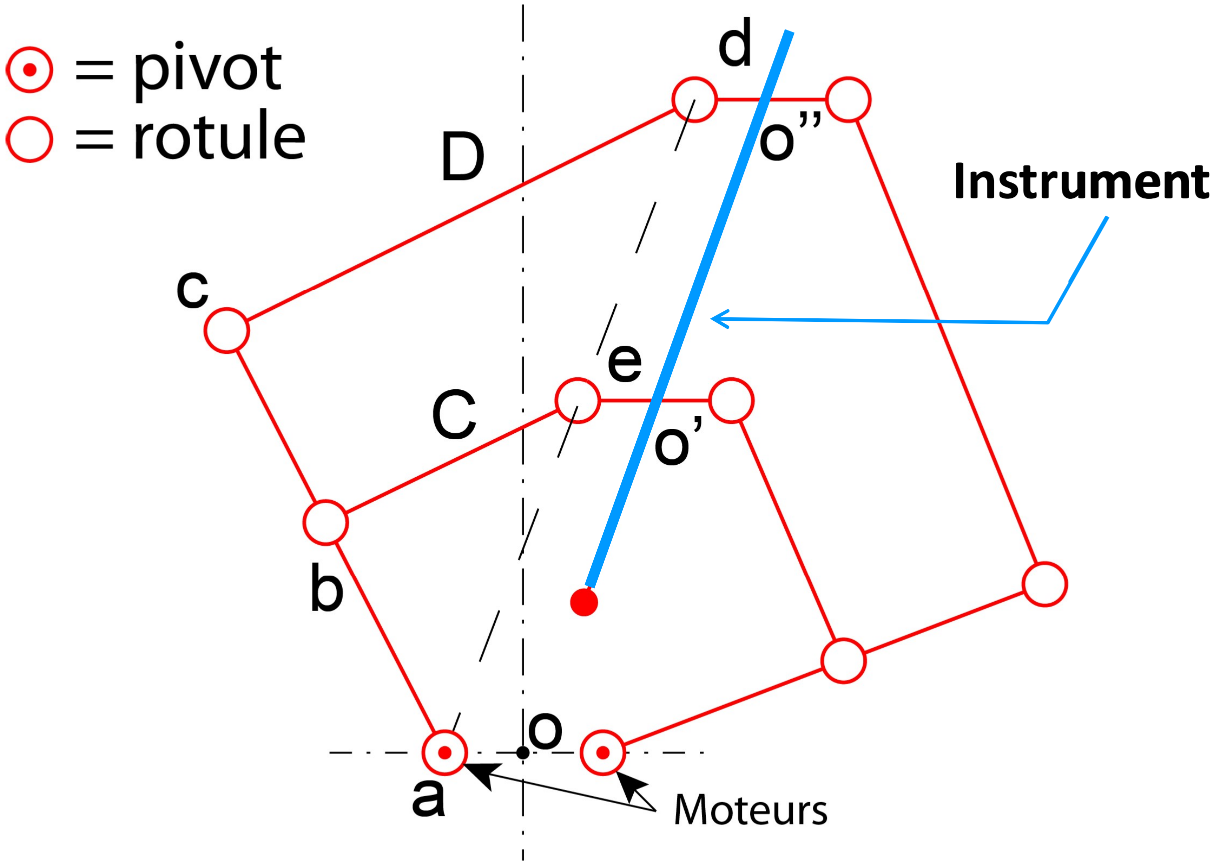
The Adept Quattro™ s650H parallel robot is specifically designed for high-speed applications in packaging, manufacturing, assembly, and material handling. The Adept Quattro robot is the only parallel robot (or "delta robot") in the world that features a patented four-arm design, advanced control algorithms, and large work envelope make the Adept Quattro the ideal overhead-mount robot for smooth motion, high-throughput applications. The Adept Quattro is powered by ultra-compact controls and embedded amplifiers, which reduces the cycle time and improves footprint efficiency.

Thales ... idea found an application !





Initial kinematics

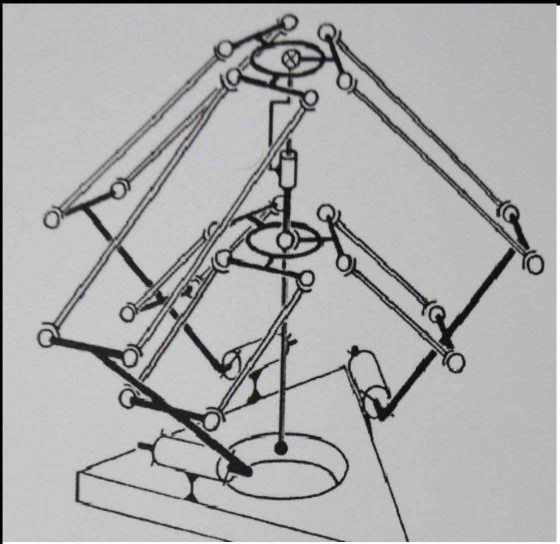


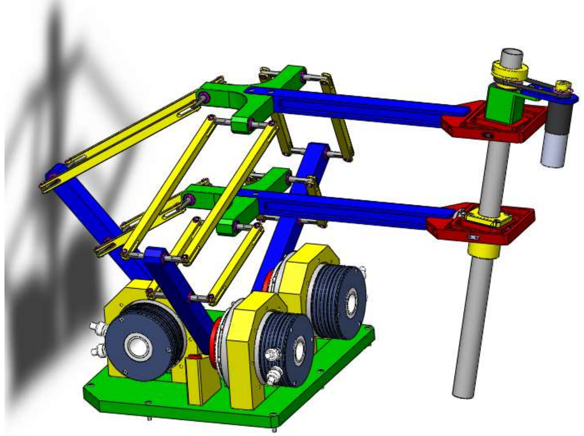
A spherical robot…..

1 translation (insertion) of the instrument

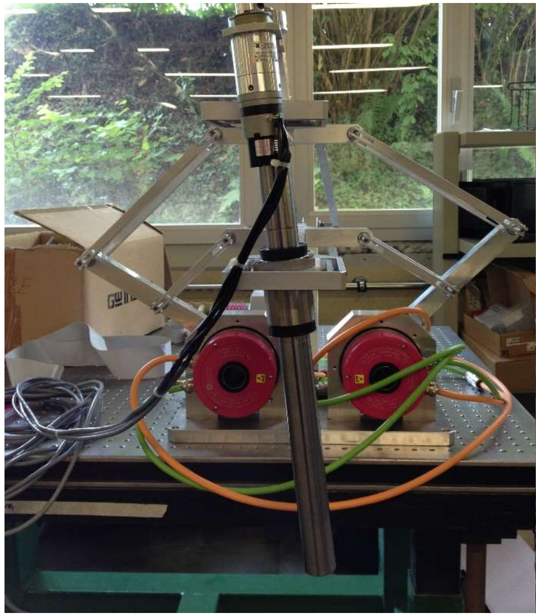
2 tilts (orientations) of the instrument

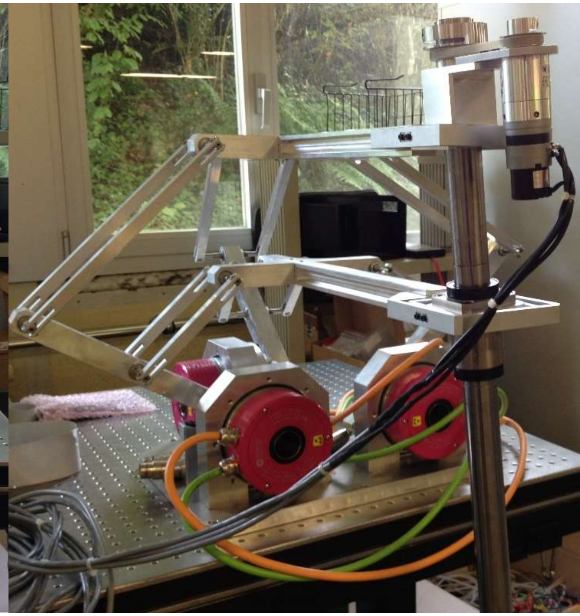
Thales … idea found an application for surgery!





……for laparoscopic surgery with an **ex-centered** tool





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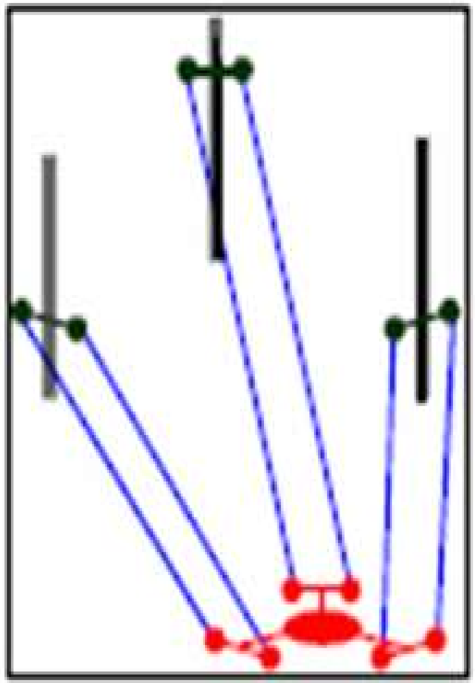
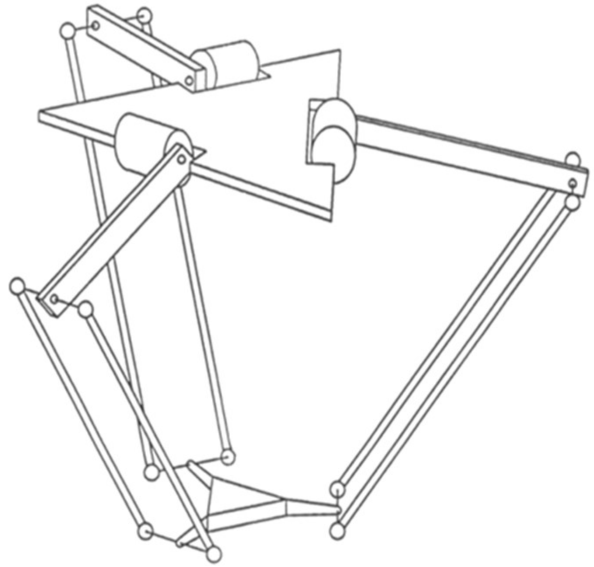
Linear Variants

Variants with linear movements

- for applications requiring stiffness.
- For applications requiring precision

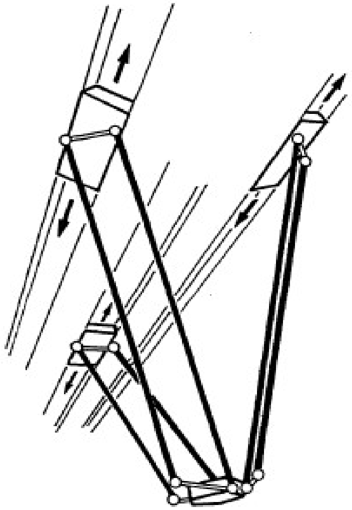


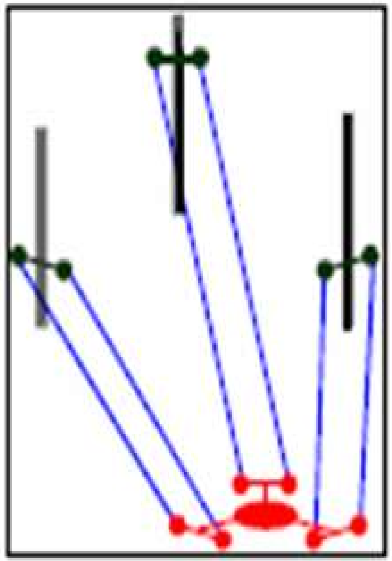


Is this comparison true?

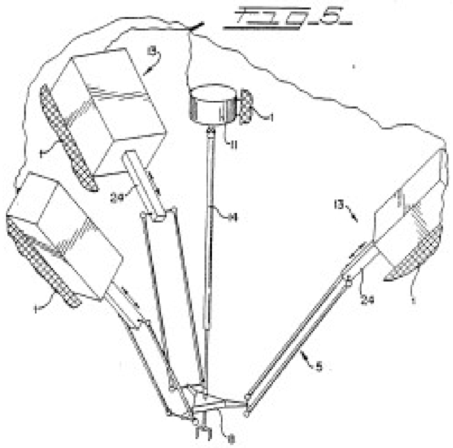
- **The speed** of the linear variants **is only limited by the actuators**
- **The stiffness** of the rotational variants is only limited by the stiffness of the arm.
- **Increasing the resolution** of the rotational variants is only limited by the sensor quality.

Types of the linear Delta



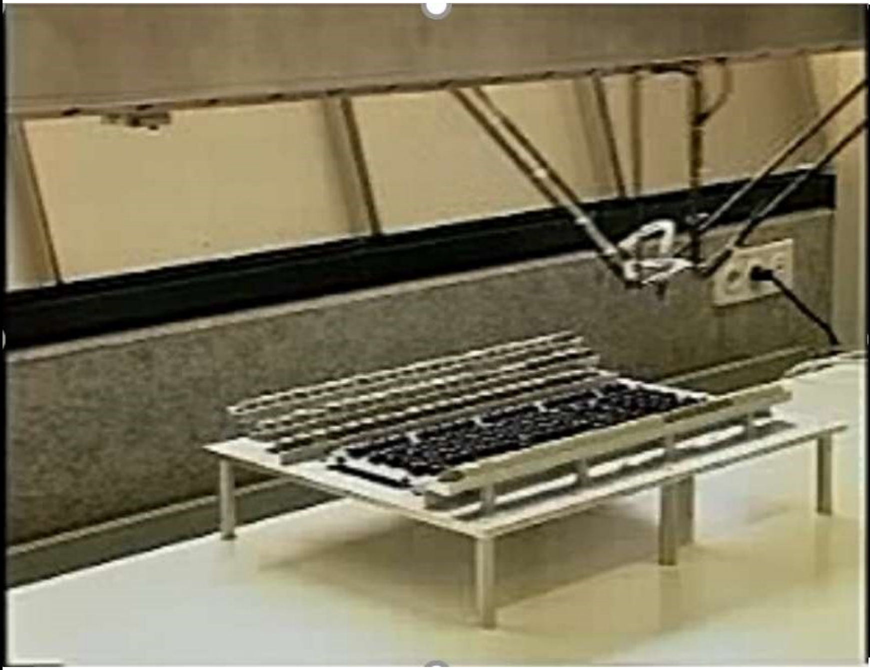


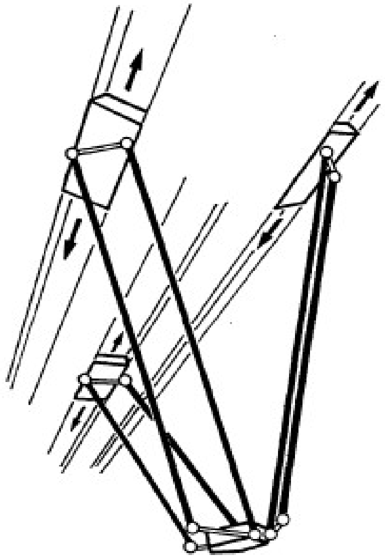
U.S. Patent Dec. 11, 1990



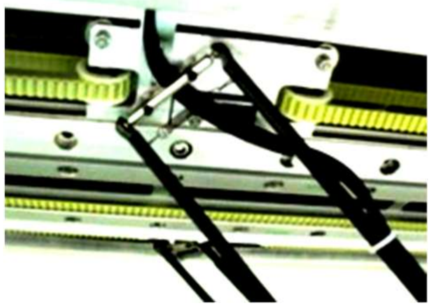
- Horizontal linear structure,
- Vertical structures,
- Orthogonal,
- Inclined guided

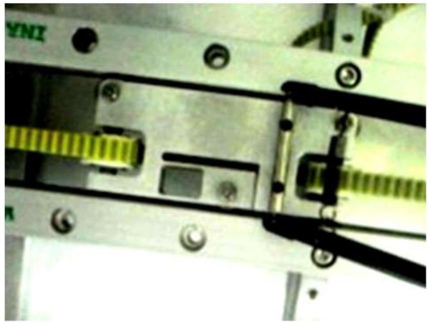
The Horizontal family



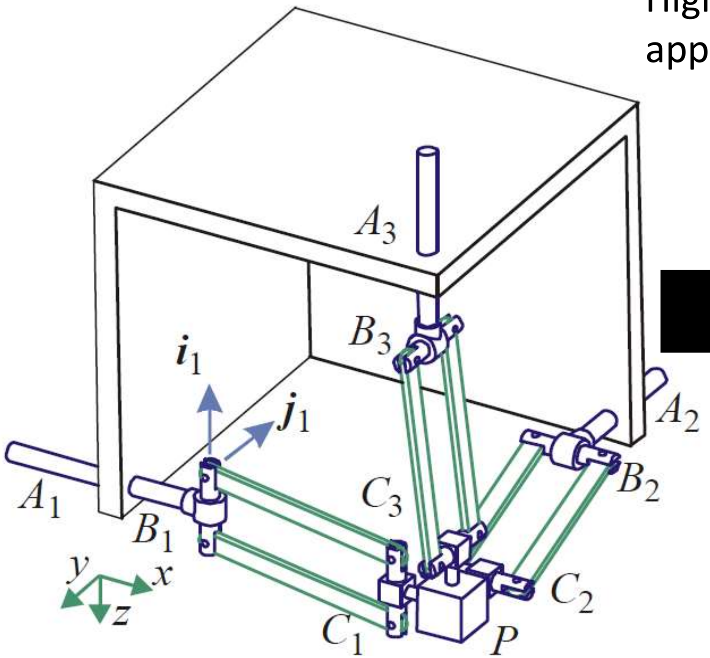


Double hoist system as a translational transmission
(FR, doulble palan)





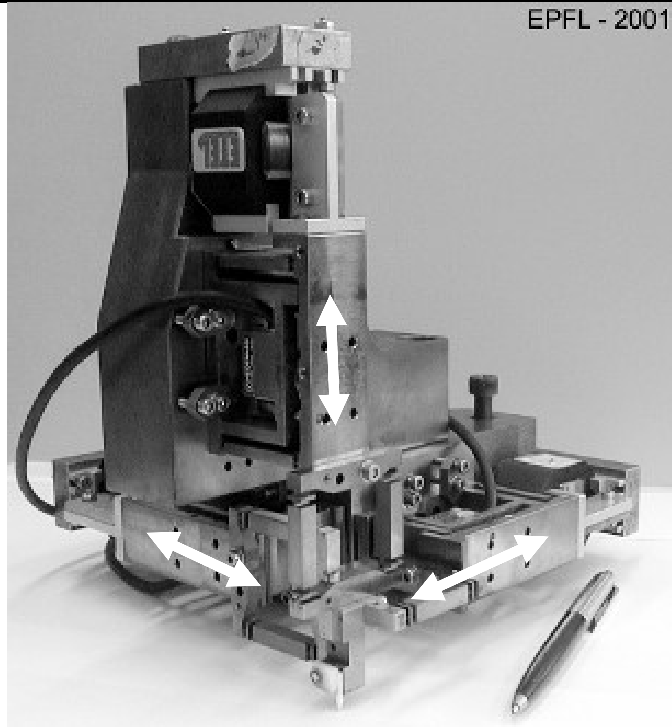
The orthogonal family



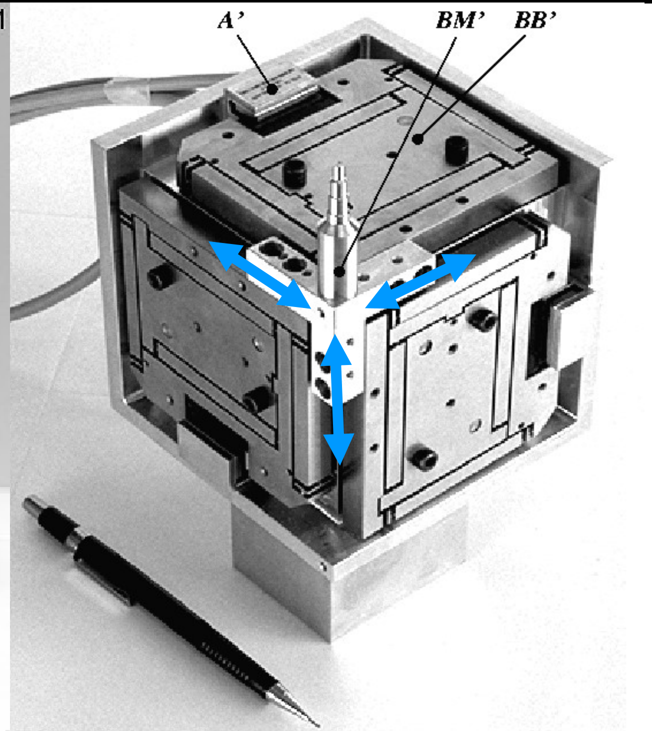
The orthoglide from IRCCyN

[!] Problem of the orthogonality of the three plans

High precision applications



MX3000 from MECARTEX SA
http://www.mecatex.ch/



Delta Cube I
Thesis, Simon Henein, EPFL

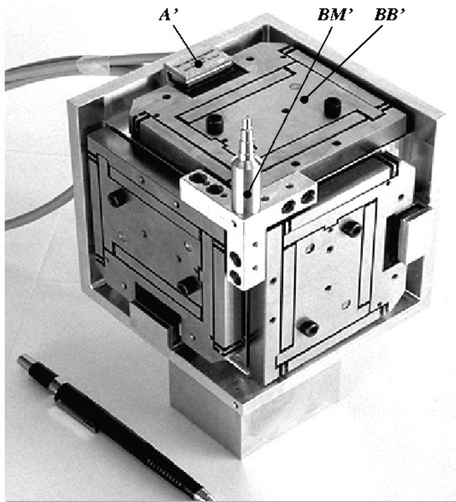
The orthogonality of the three plans is solved through a monolithic machining

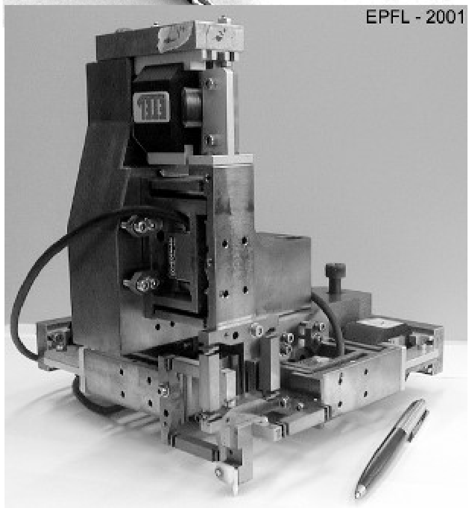
More details

This Delta structures called "**Delta Cube**" reach a repeatability of **+/-10nm**.

"**Delta Cube I**" that has a travel of +/- 1mm in each direction.

"**Delta** Cube II" has a travel of +/-4 mm in each direction with a proper frequency of 350Hz.



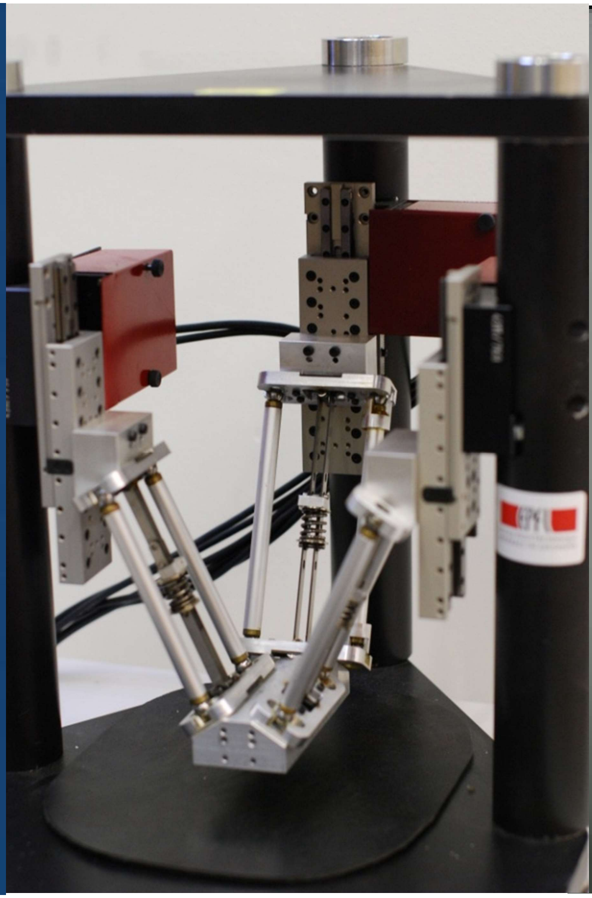


E. Lubrano, R. Clavel [ISR 2010]

Developments and applications

The Vertical family

1. Assembly for microEngineering



The Vertical family

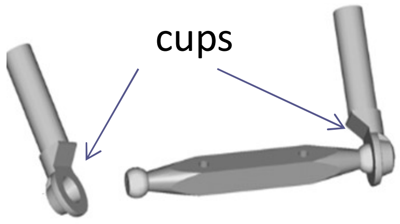
2. Towards Pin insertion for watch industry

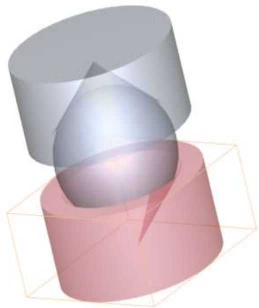
- Stiffnes
- Speed
- Simplicity

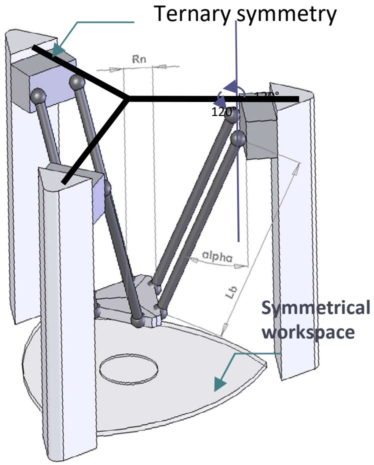
Modify the spherical joints

Adapt the parallel bars

Use ball screw to increase Available insertion forces <=300N







Developments and applications

The Vertical family

2. Towards Pin insertion for Watch Industry

Length of parallel bars:	*300* ***mm***
Space resolution:	*0.1-0,25* ***mm***
Vertical resolution (center):	*0.1* ***mm***
Velocity:	*0.4* ***m/s***
Acceleration:	50 ***m/s²***
Vertical force:	≤ 350***N***
Stiffness:	50***N/mm*** ***(5.10⁷N/m)***
Working space:	ϕ = *240 – 280* ***mm***
	H = *80* ***mm***

Developments and applications

The Vertical family

The Inclined **Keops-** Advantage 1

Workspace .vs. robot size

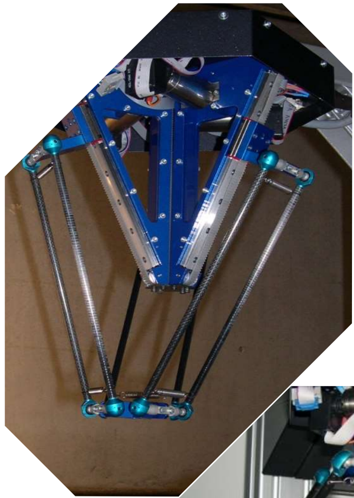
Resolution on the linear axis is **7.5 μm**;

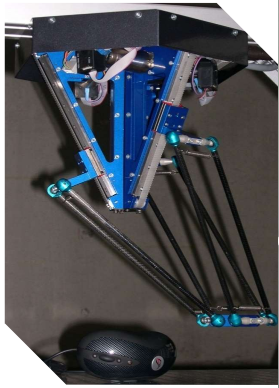
the worst resolution in the workspace is

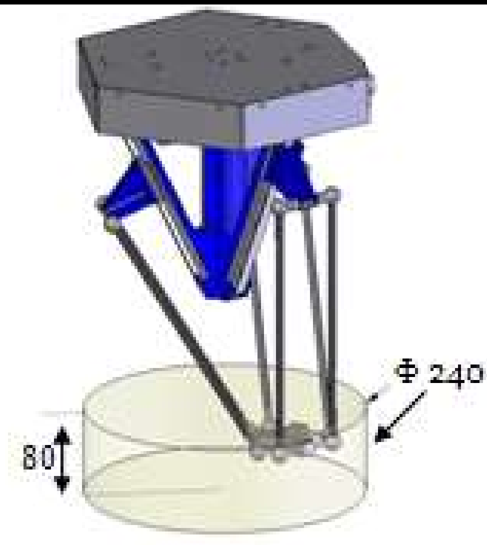
better than **20μm**;

the velocity can easily reach **3.5m/s** at

the acceleration value of **3.5g**.



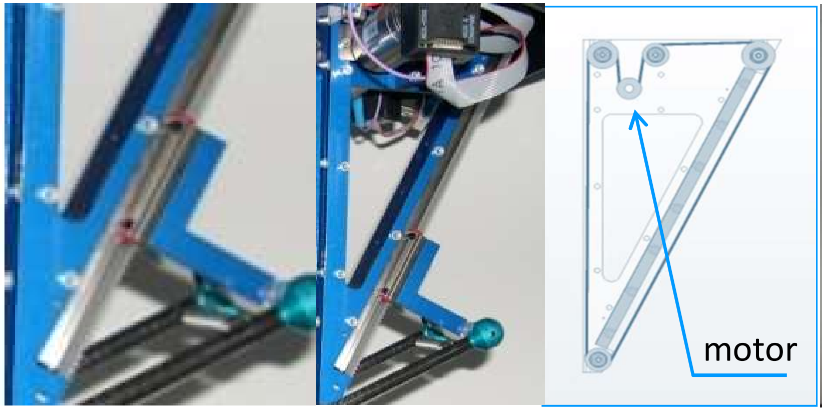




The Vertical family

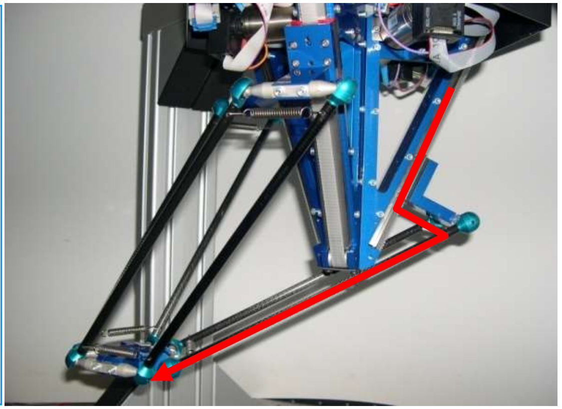
The Inclined **Keops-** Advantage 2

Simplicity



The Inclined **Keops-** Advantage 3

Stiffness at the **extremity** of the volume

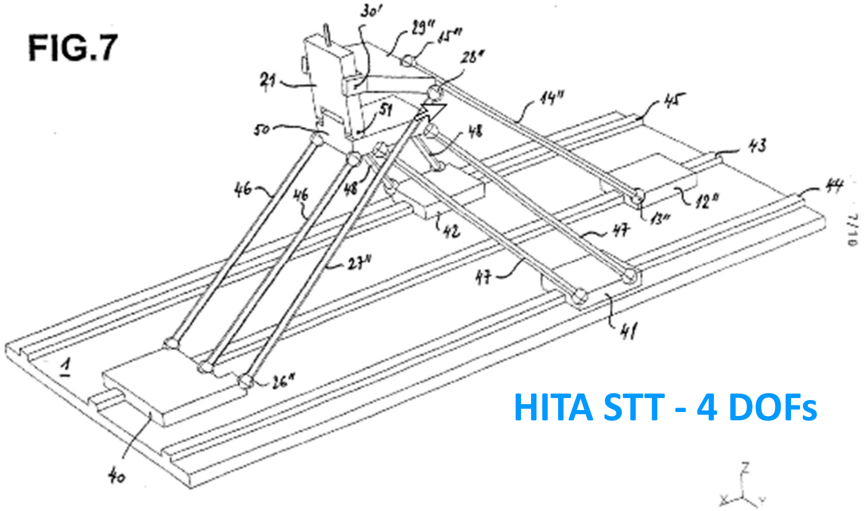


What else…

1µm - sensors integrated to Schneeberger guideways.

The Horizontal family - Tool Machining

FIG.7



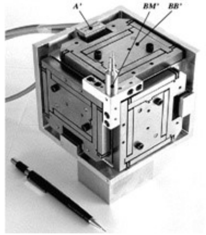
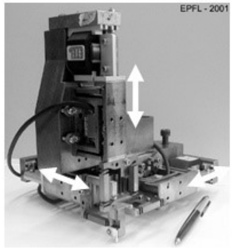
HITA STT - 4 DOFs

Extension of the linear horizontal Delta to have one additional degree of freedom.

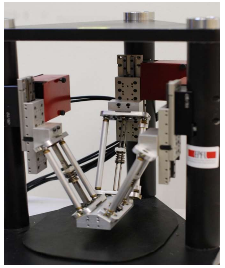
STT: Stiffness Tracking Technology.

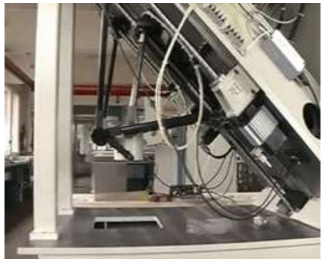
HITA STT, EPFL, 4 DOFS / XYZ and one tilt
[ref Willemin Macodel]

Plenty of Δ -structures.....

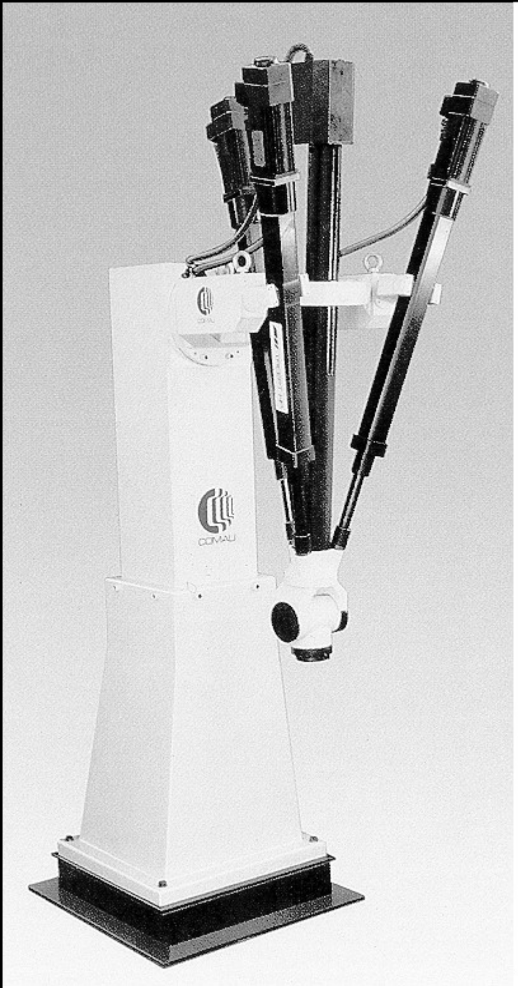



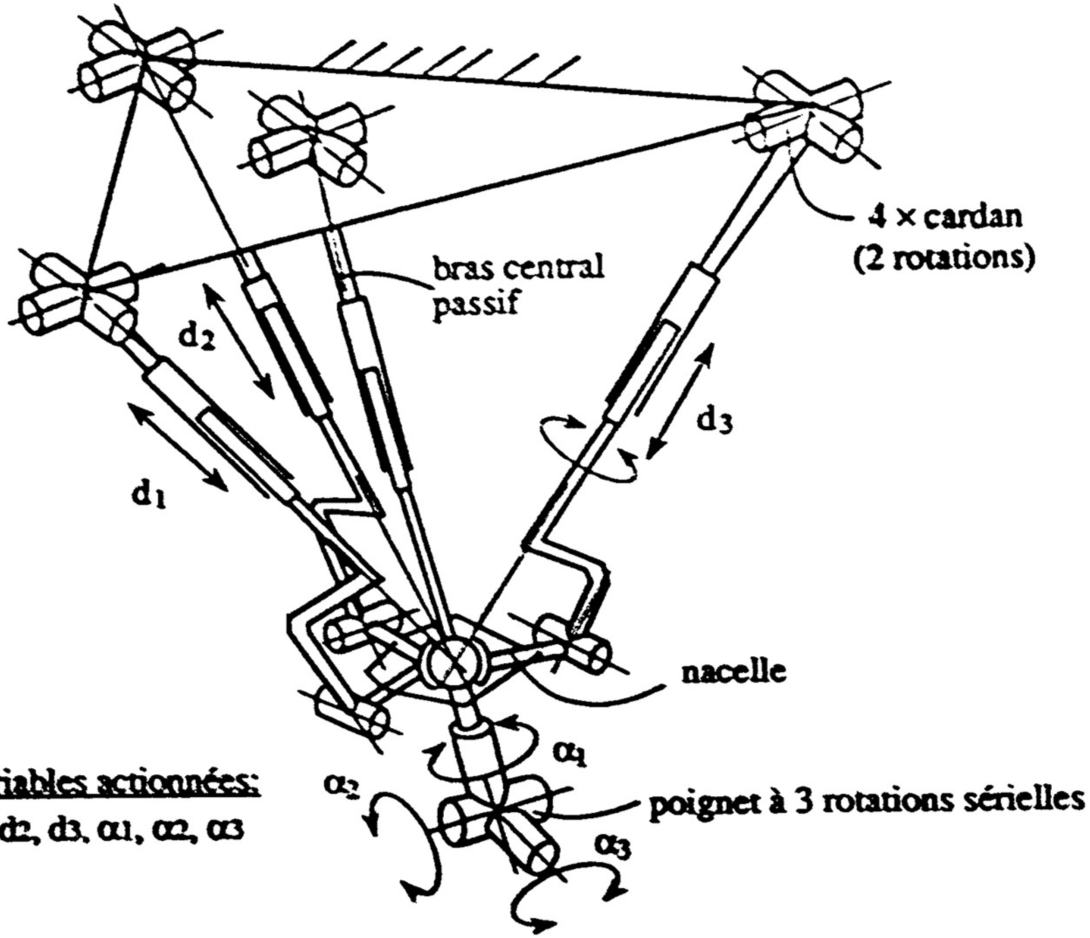



The Tricept (Tetrabot)

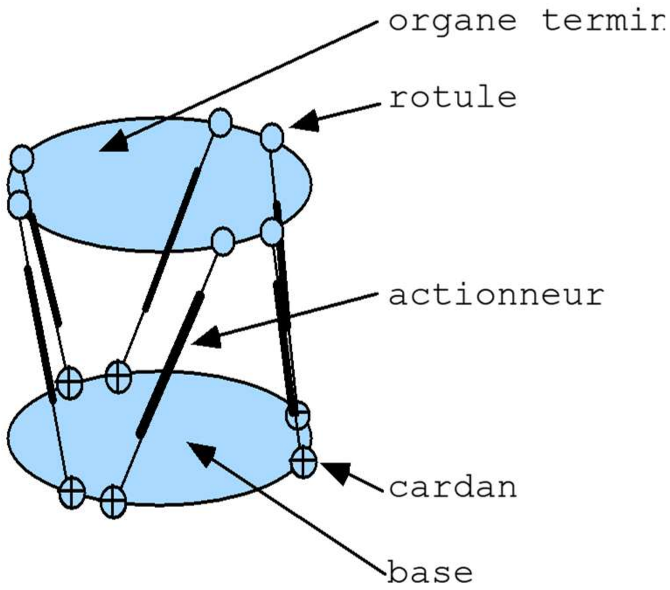




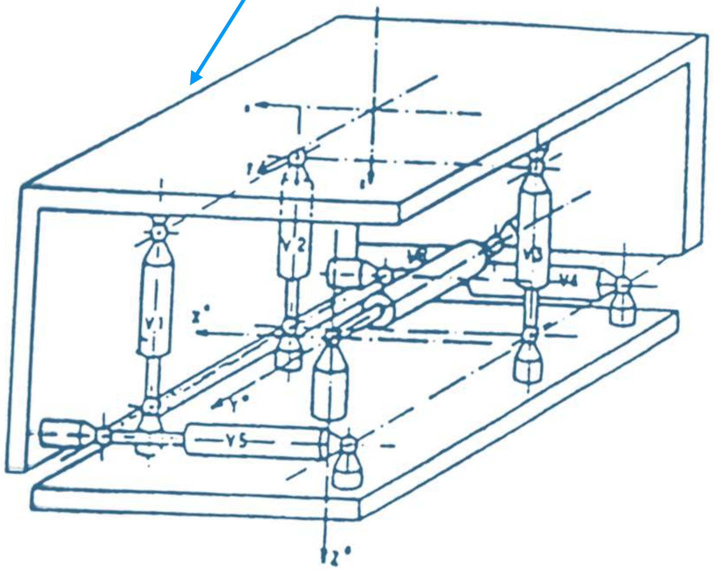
Variables actionnées:
d1, d2, d3, α1, α2, α3

Platforms 6 DOFs

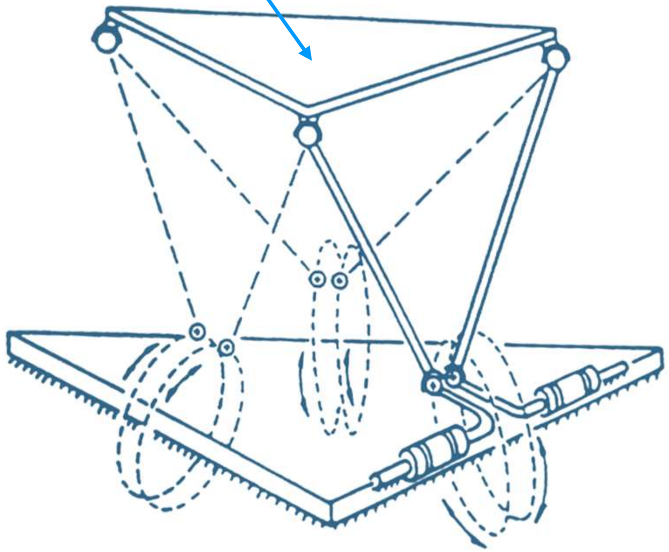
GOUGH-STEWART (1962)



ARTIGUE (1984) and HUNT (1983)



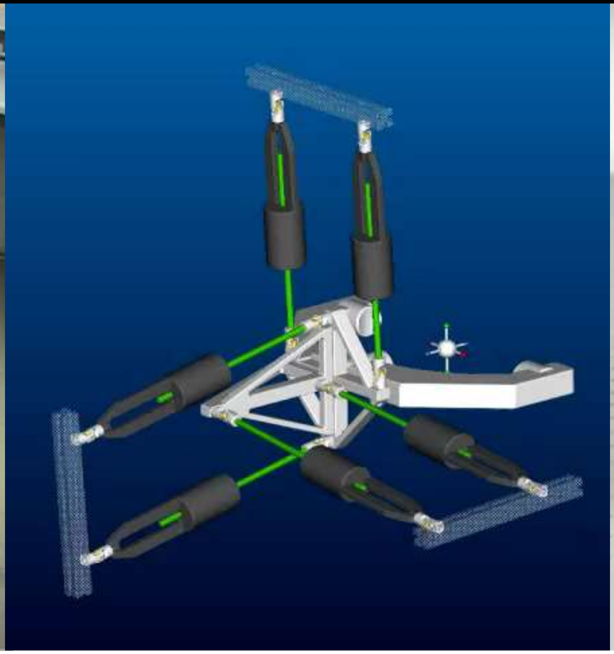
• Decoupled for small motions



• Actuators fixed to base

Gough-Stewart vs Hunt vs Artigue

Artigue 3x2x1



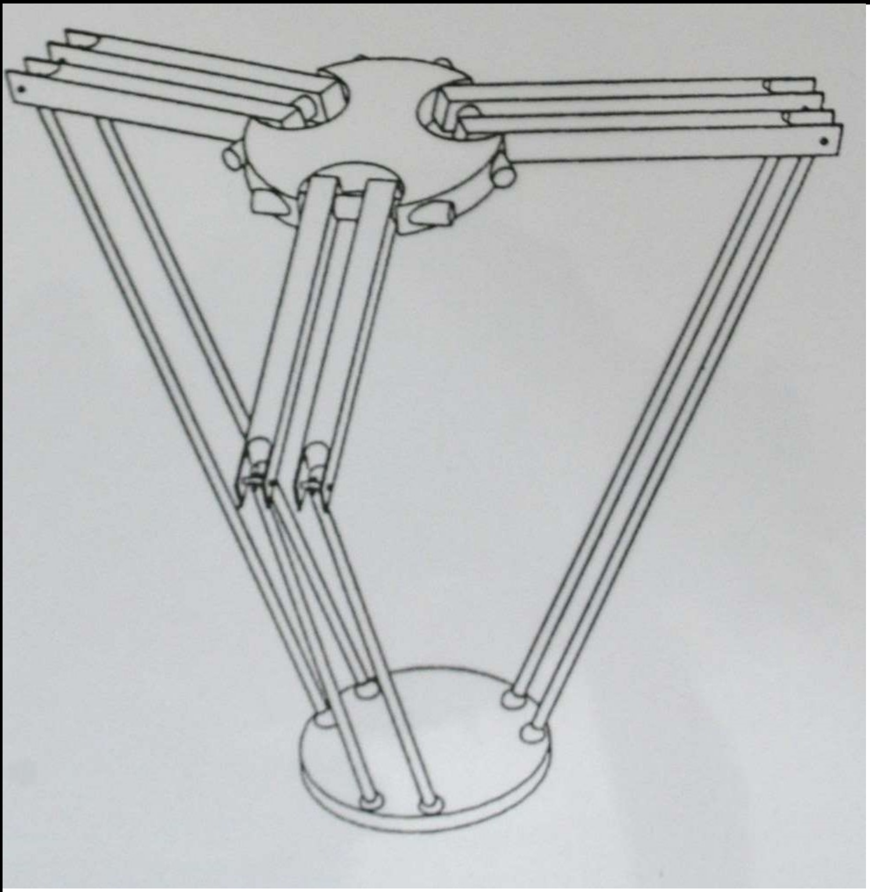
Artigue 2x2x2

Gough-Stewart
Hexapod [ref. Symetrie]

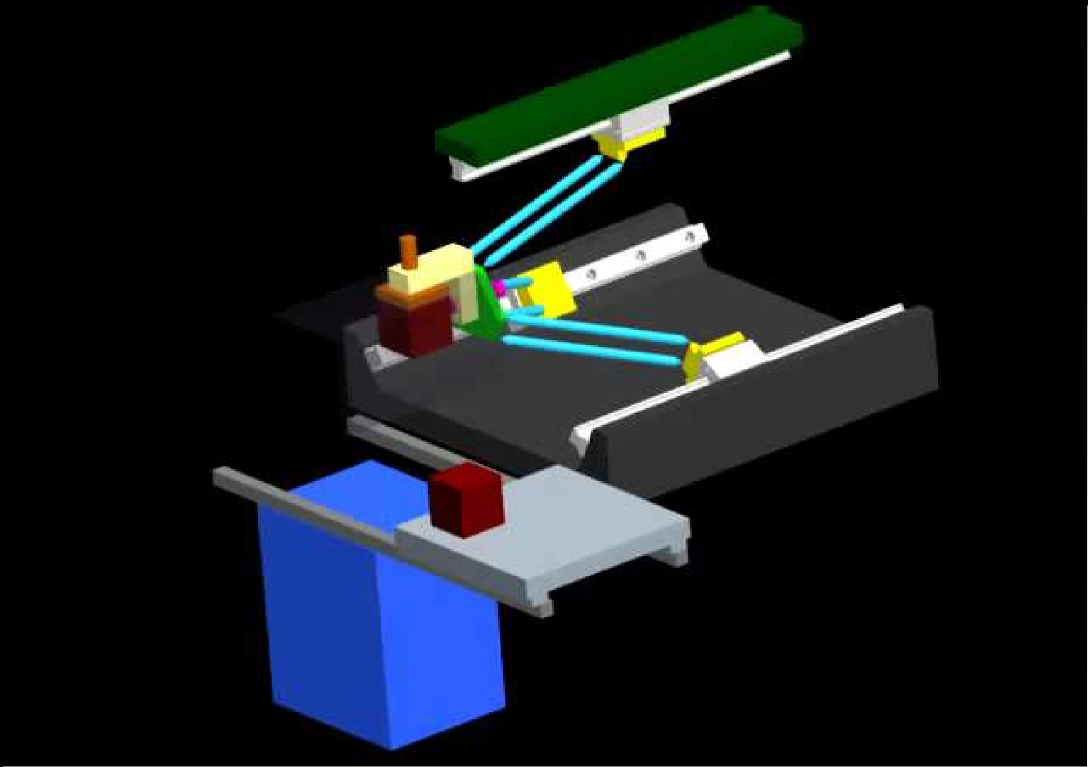
Hunt
Rotational Stewart

- «**Artigue**» has more **decoupled movements** than «**Gough-Stewart**» and «Hunt»
- «**Artigue 2x2x2**» is **even more decoupled** than «**Artigue 3x2x1**»
- All the **linear variants are stiffer** than the Rotational «Hunt»
- «**Hunt**» is **more dynamic**, has **bigger workspace** than «**Gough-Stewart**»

Platform 6 DOFs inspired from the Delta



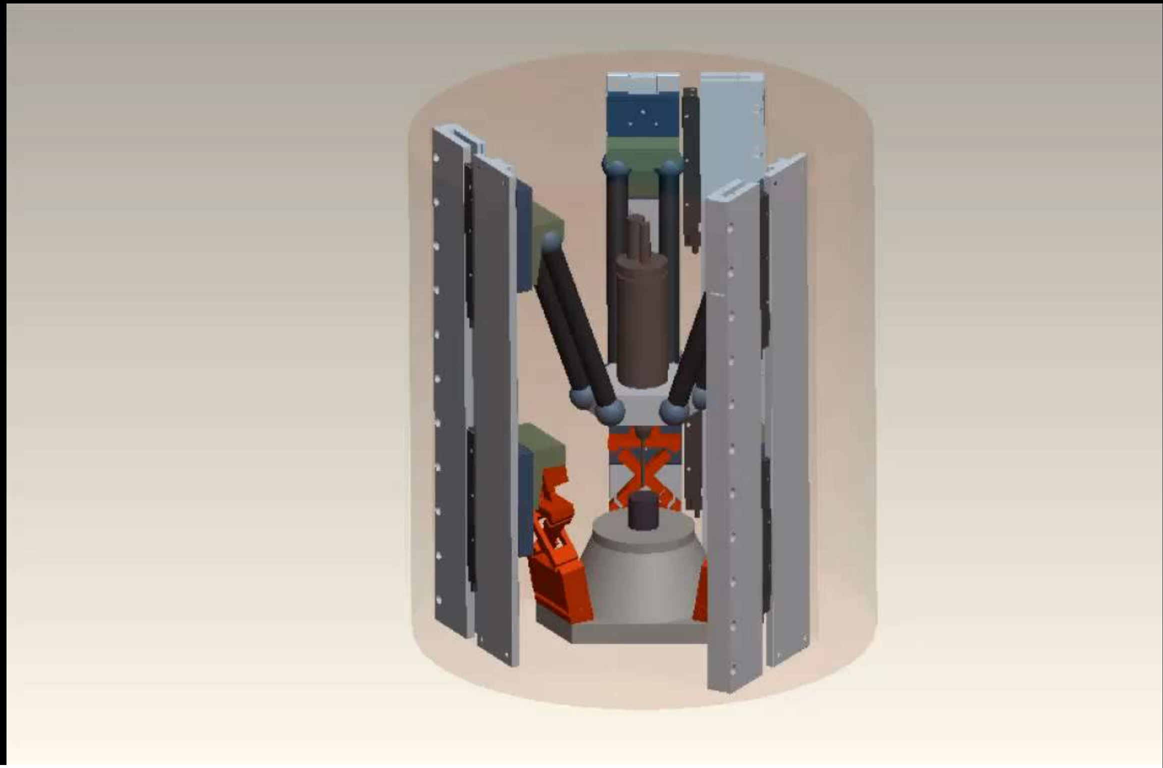
Hybrid solutions to obtain more DOFs



Parallel + serial

XYZ using the Delta linear + serial double-tilt

Ref. Unitechnology SA / Laser polishing



Right and Left Hand combination

XYZ using the Delta linear + Orion double-tilt + Z

Ref. Mecartex SA /Micro EDM

Exercise 1

Prove that the Grübler and Kinematic Loop formulas for mobility calculation are valid for serial structures. Use the example of the 3 axis angular kinematics.