Kinematics, dynamics and control of a hybrid parallel-serial redundant manipulator

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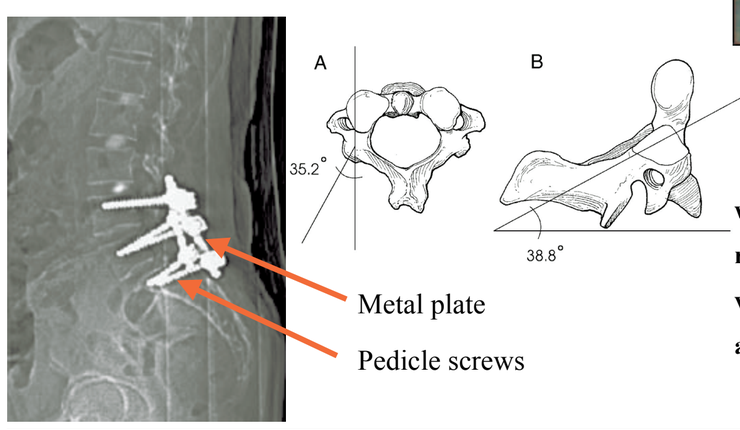
Applications

SURGICAL ROBOT

- high precision and dexterity
- mini-invasive surgery
- easier surgical procedure planning
- intra-surgical co-ordination with other medical equipment



INTERVERTEBRAL PEDICLE SCREW INSERTION

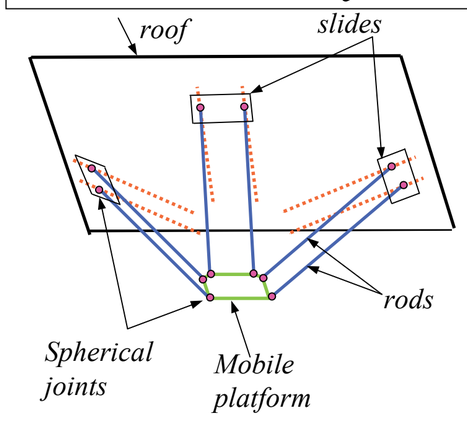
working space: 400x400x300 mm

rotations: +\- 40°

velocity: 1.5 m/s

acceleration: 20 m/s²

Hybrid kinematic structure



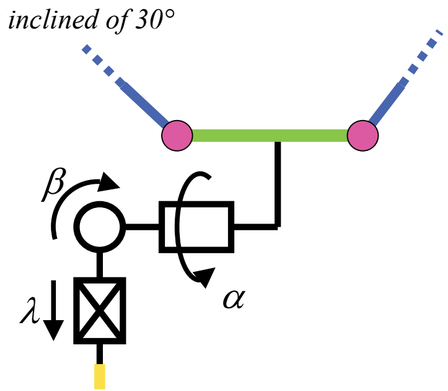
Parallel structure

3 pairs of parallel rods → *The **platform** translates*

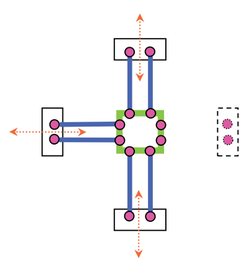
- ***spherical joints** at the ends*
- ***slides** on **guides** inclined of 30°*
- *3+1 axes*

Serial wrist

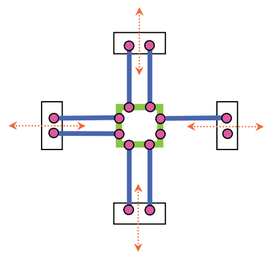
- *α rotation*
- *β lifting*
- *λ drill **tip** movement (redundant)*



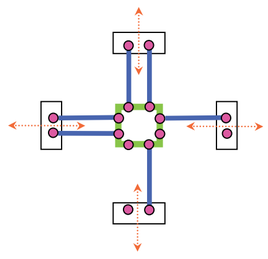
Parallel part re-configurability



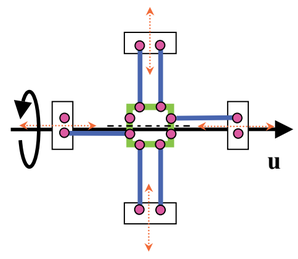
- *3 d.o.f.*
- *3 motors*
- *isostatics*
- *pure translation*



- *3 d.o.f.*
- *4 motors*
- *over-constrained*
- *structure preloaded to reduce backlash and singularity*
- *improved workspace*



- *4 d.o.f.*
- *4 motors*
- *isostatics*
- *4 dof "complex" rototranslation*
- *improve rotation of serial wrist*



- *4 d.o.f. (type B)*
- *4 motors*
- *isostatics*
- *translation plus rotation around axis **u***

Kinetostatic analysis

actuator velocity **gripper velocity**

$$\dot{Q} = JV_g$$

$$\begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = \begin{bmatrix} a_{1x} & a_{1y} & a_{1z} \\ a_{2x} & a_{2y} & a_{2z} \\ a_{3x} & a_{2z} & a_{3z} \end{bmatrix} \begin{bmatrix} V_{gx} \\ V_{gy} \\ V_{gz} \end{bmatrix}$$

actuator forces **gripper forces**

$$\begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix} = J^T \begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix}$$

Slide:

P_i **position**

u_i **unit vector**

$\dot{q}_i$ **linear velocity**

V_i **vector velocity**

$\ddot{q}_i$ **linear acceleration**

A_i **vector acceleration**

$$a_i = \frac{1}{\lambda_i \cdot u_i} \lambda_i$$

platform:

V_{gi} **vector velocity**

A_{gi} **vector acceleration**

leg:

L_i **leg vector**

l_i ***length***

λ_i ***unit vector***

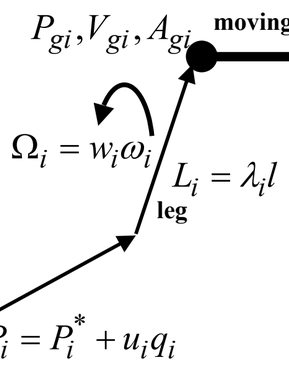
w_i **unit vector of velocity**

ω_i **angular velocity (module)**

Ω_i **angular velocity (vector)**

$\dot{\omega}_i$ **angular acceleration (module)**

$\dot{\Omega}_i$ **angular acceleration (vector)**



position analysis

$$\begin{cases} \left\| P_{gi} - P_i \right\| = l \\ P_i = P_i^* + u_i q_i \end{cases}$$

velocity analysis

$$V_{gi} = u_i \dot{q}_i + \Omega_i \times L_i = u_i \dot{q}_i + (w_i \times \lambda_i) \omega_i l$$

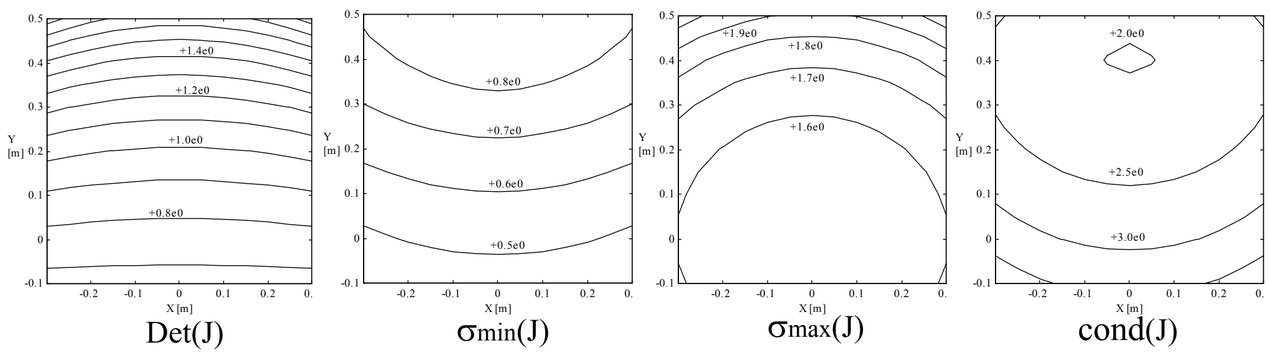
$$w_i \cdot \lambda_i = 0 \qquad \dot{q}_i = \frac{\lambda_i \cdot V_{gi}}{\lambda_i \cdot u_i} \qquad \left\| \omega_i \right\| = \frac{V_{gi} - V_i}{l}$$

acceleration analysis

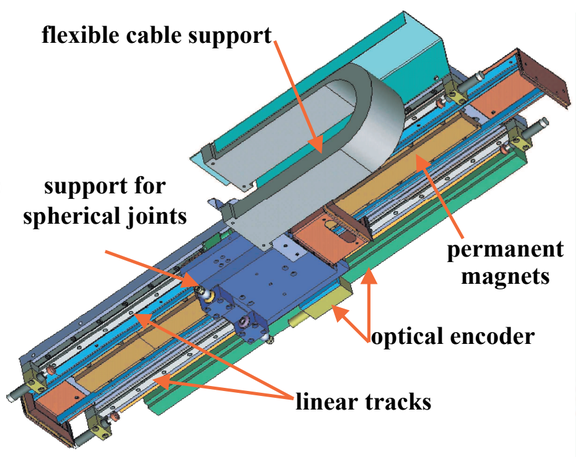
$$A_{gi} = u_i \ddot{q}_i + \dot{\Omega}_i \times L_i + \Omega_i \times (\Omega_i \times L_i) = u_i \ddot{q}_i + \dot{\omega}_i w_i \times \lambda_i l - \omega_i^2 \lambda_i l_i$$

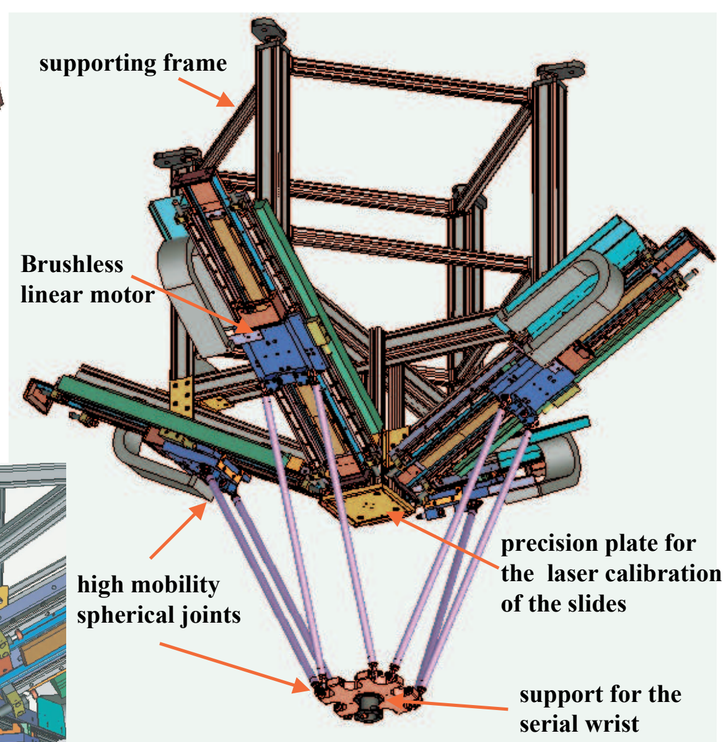
$$\ddot{q}_i = \frac{\lambda_i \cdot (A_{gi} + \omega_i^2 \lambda_i l)}{\lambda_i \cdot u_i}$$

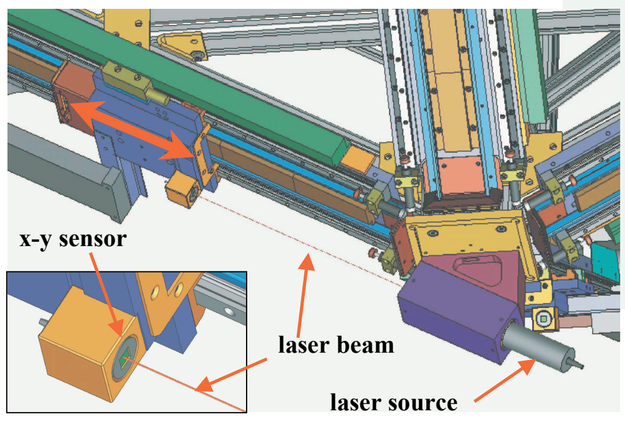
Geometry optimisation



Parallel structure







Calibration is performed moving the axis and measuring the x-y position of the incoming beam

Calibration

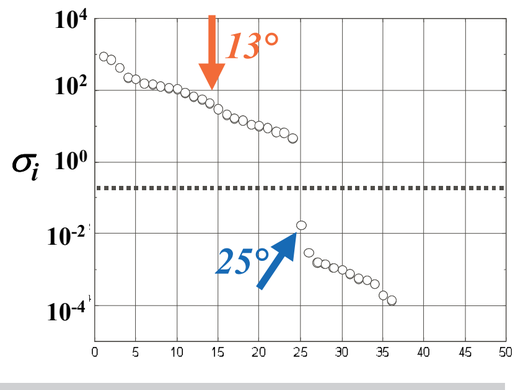
36 parameters
24 significant combinations of parameters

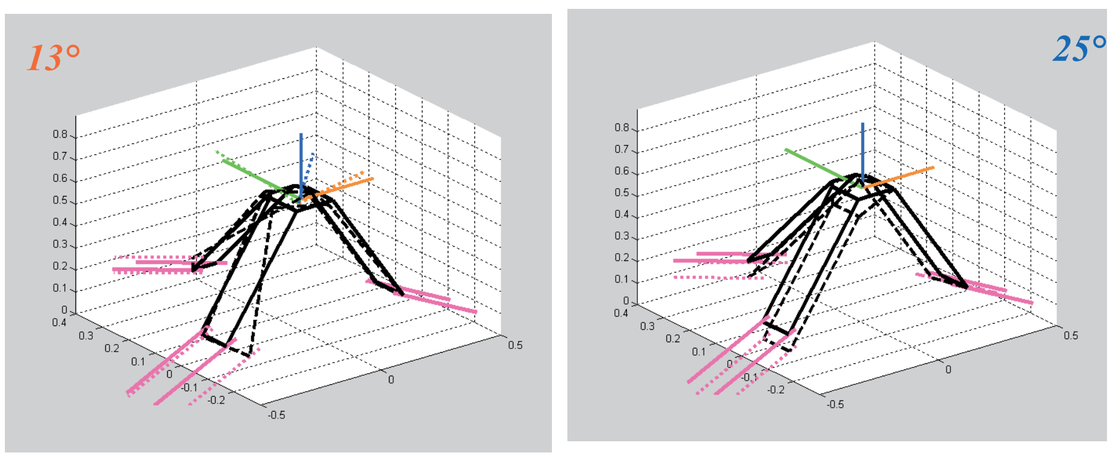
ideal geometry
with errors

calibration simulations predict the following accuracy

5mm / 50 mrad **before calibration**

0.5 mm / 3 mrad **after calibration**

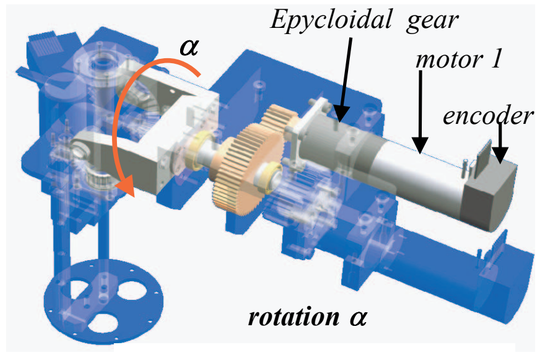


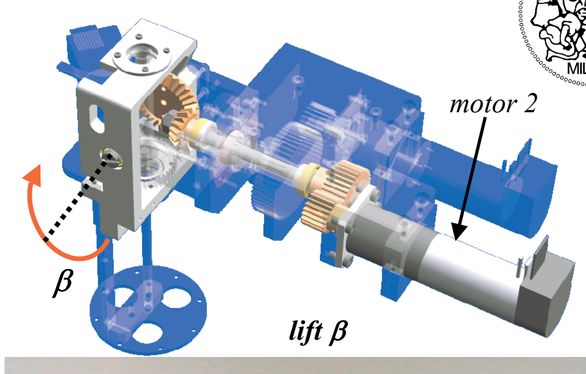


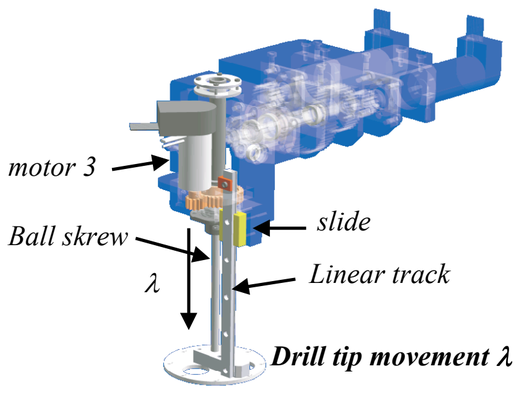
effect of significant structural errors (left) and non-significant errors (right)

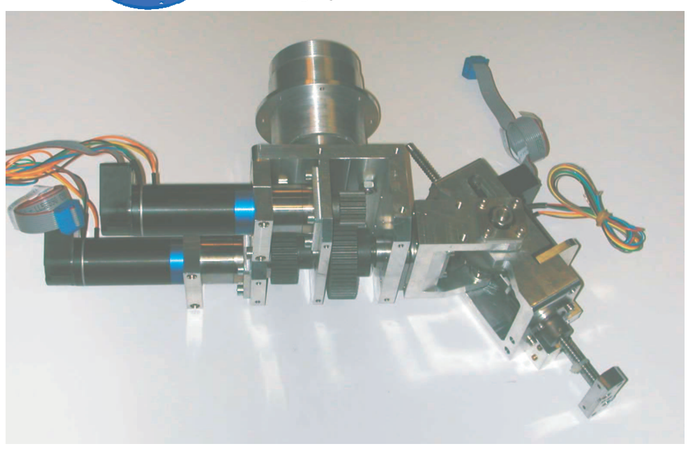
Serial wrist

(in cooperation with *Politecnico di Milano*)









References

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-D.Tosi, G. Legnani, P. L. Magnani, *Calibration of "CHEOPE" a parallel-serial redundant manipulator*, Proc. of AIMETA 2003, Ferrara 9-12 Sept. 2003