Tricept Parallel Robot MSA and VJM Modeling & Fanuc R2000 with Positioner VJM, Elastostatic Calibration, Geometrical Calibration and Redundancy Resolution

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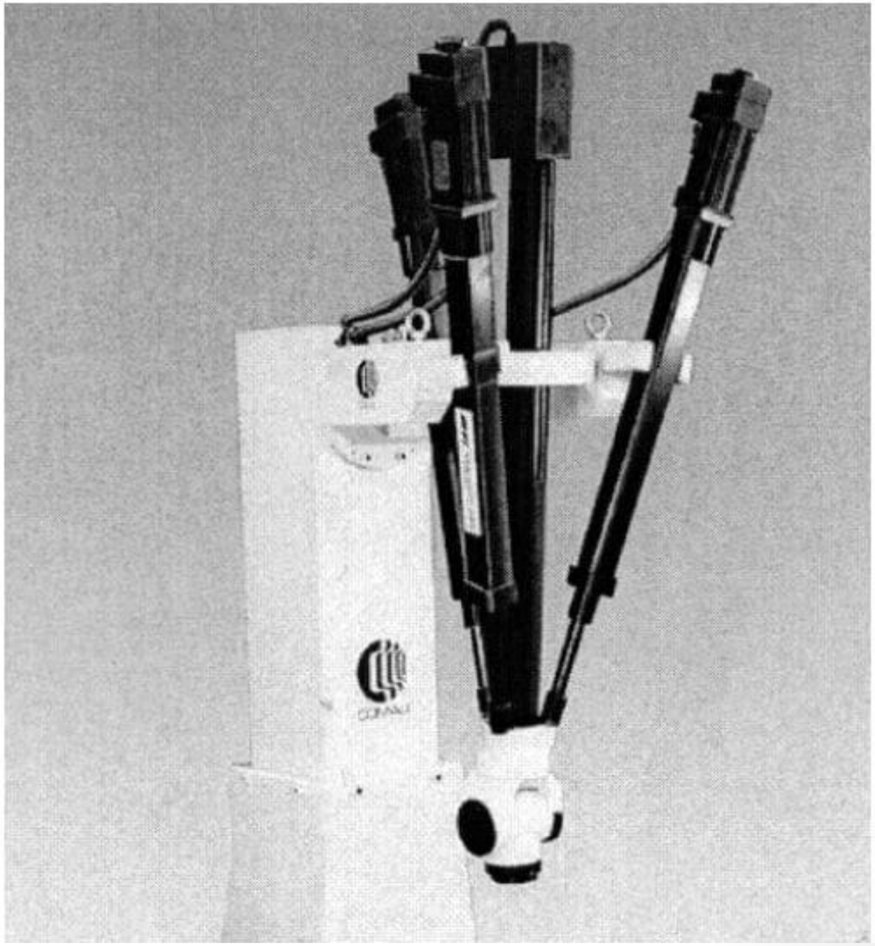
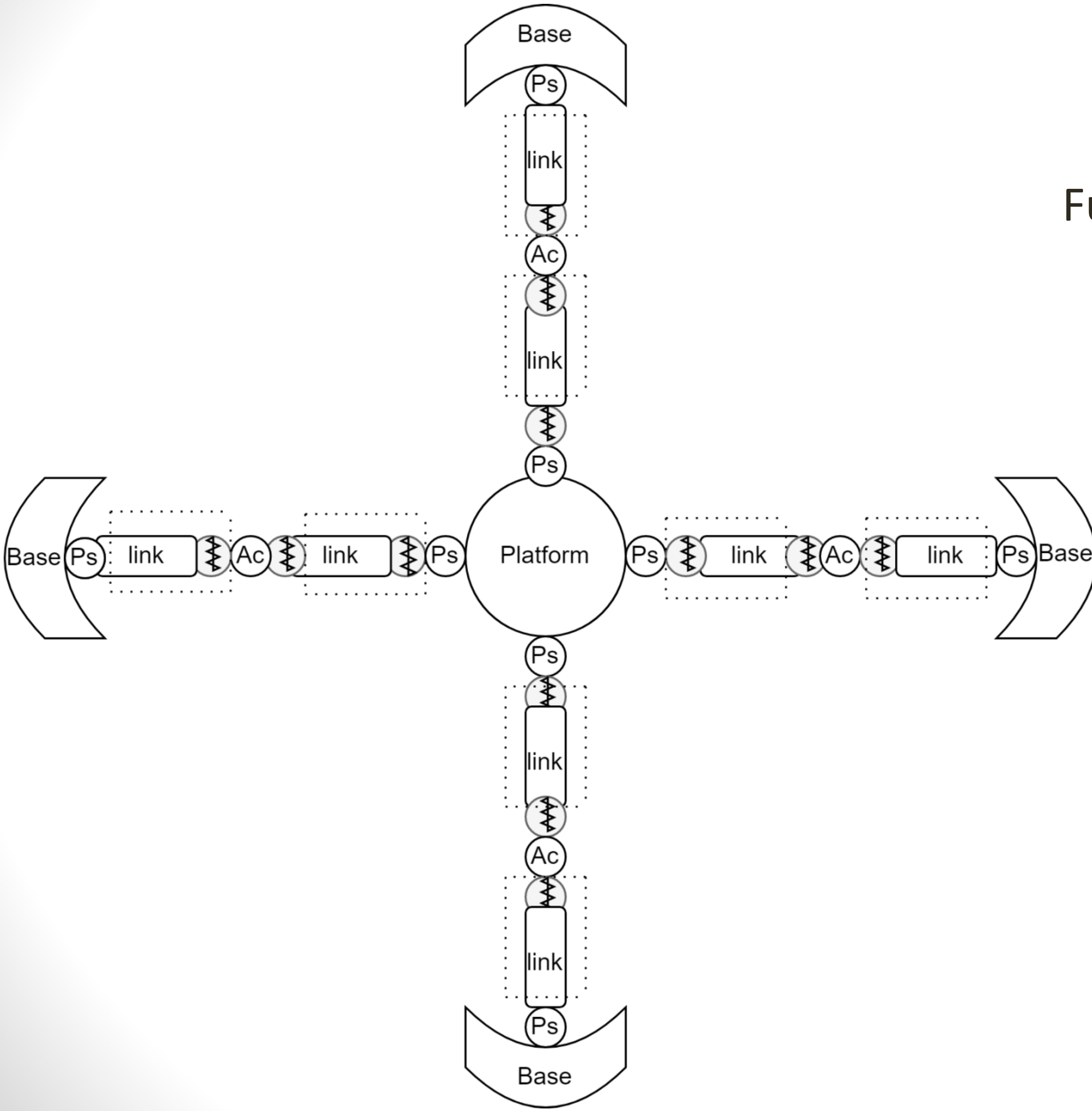
Tricept

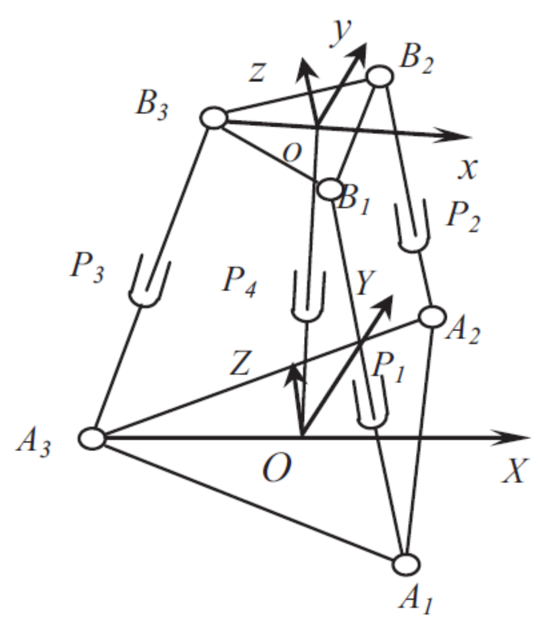
Tricept robot was invented by Dr. Neumann in 1988, it is a 5 degree of freedom hybrid mechanism composed of 3UPS-UP parallel mechanism in series with a 2R series mechanism, it has the advantages of high precision, rigidity, stability and so on, and is widely used in industrial production such as parts milling, welding, painting, handling, assembly, etc..



Tricept VJM Moduling



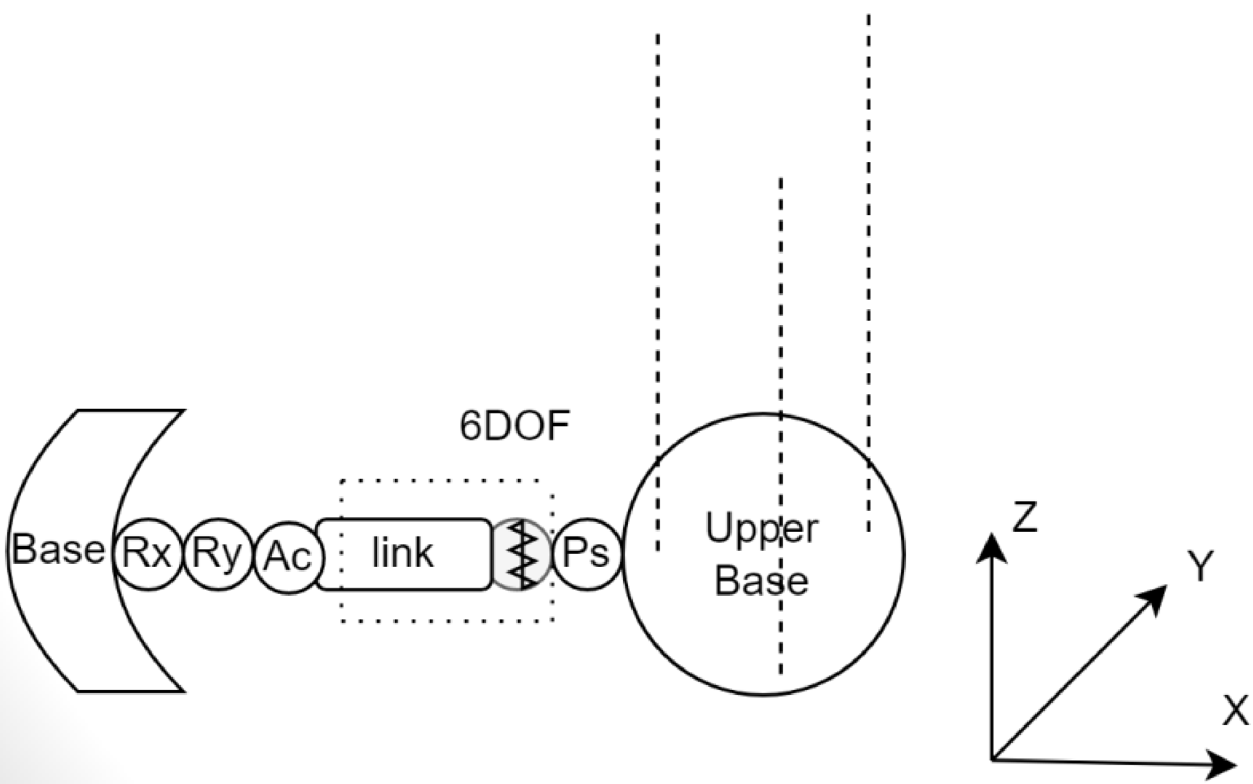
- Full VJM Model



Tricept VJM Moduling

- Simplified VJM Model

$$T = T_{base} * R_x(q_1) * R_y(q_2) * T_z(\theta_1) * T_z(l_1) * T_{3D}(\theta_i, 2-7) * R_x(q_3) * R_y(q_4) * R_z(q_5) * T_{Ubase} \quad (39$$



Tricept VJM Modeling

- Simplified VJM Model

$$T = T_{base} * R_x(q_1) * R_y(q_2) * T_z(\theta_1) * T_z(l_1) * T_{3D}(\theta_i, 2-7) * R_x(q_3) * R_y(q_4) * R_z(q_5) * T_{Ubase} \tag{39}$$

$$J_q = [\, J_1 \;\; J_2 \;\; J_3 \;\; J_4 \;\; J_5 \,] \qquad J_{6*5}$$

$$J_\theta = [\, J_1 \;\; J_2 \;\; J_3 \;\; J_4 \;\; J_5 \;\; J_6 \;\; J_7 \,] \quad J_{6*7}$$

$K \quad system=$

$$\begin{matrix} [\,0 & J_\theta & J_\theta] \\ [J'_\theta & -K_\theta & 0\,] \\ [J'_q & 0 & 0\,] \end{matrix}$$

$$K_{18*18}$$

$$K_{\theta\ 7*7}$$

Tricept VJM Modeling

- Simplified VJM Model

- Now to find Kc:

$$\begin{bmatrix} \mathbf{0} & \mathbf{J}_\theta & \mathbf{J}_q \\ \mathbf{J}_\theta^T & -\mathbf{K}_\theta & \mathbf{0} \\ \mathbf{J}_q^T & \mathbf{0} & \mathbf{0} \end{bmatrix}^{-1} = \left[\begin{array}{c|c|c} \mathbf{K}_C & * & * \\ \hline * & * & * \\ \hline * & * & * \end{array}\right]$$

- And calculate Δt from the following equation:

$$\mathbf{F} = \mathbf{K}_C \cdot \Delta\mathbf{t}$$

Tricept VJM Modeling

- Deflections

We calculate Kc for each leg then: $K_c = \sum K_i \quad ; i = 1 - 3$

Editor - C:\Users\new--laptop\Downloads\innopolis\Advanced Robotics\project\Tripteron_robot_VJM\Tricept with A\VJM.m

VJM.m | Jacobian_q.m | k_cylinder.m | +

```
F = [100,100,100,0,0,0]';

count = 1;

Kth1 = 1000000;

E = 70 *10e5; %Young's modulus
G = 25.5*10e5; %shear modulus
d = 10*10e-2;
l= 0.8;
K11 = Kth1;
K22 = k_cylinder(E,G,d,l);

Ktheta = [K11, zeros(1,6);
            zeros(6,1), K22];
```

Command Window

```
delta =

   1.0e-04 *

   -0.0000
    0.0000
    0.4109
    0.0000
    0.0000
   -0.0000
```

Tricept MSA Modeling

- We will show here our paper on overleaf:

- https://www.overleaf.com/project/62568740a75a7946f334584a
- Code:
- https://colab.research.google.com/drive/1o2XfpdWgn7ePPqQt6VqoQ-vdG7Yz0ZWs#scrollTo=h4B83yQ_1Ri0

Fanuc R2000 with Positioner

Fanuc R2000 with Positioner

- VJM Model:

$$T = T_{base} * T_z(l_0) * R_z(\theta_1) * T_z(l_1) * T_{3D}(\theta_i, 2-7) * R_y(\theta_8) *$$
$$T_z(l_2) * T_{3D}(\theta_i, 9-14) * R_y(\theta_15) * T_z(l_3) * T_{3D}(\theta_i, 16-21) * T_{Tool} \quad (40)$$

```
J14 = [T14(1,4), T14(2,4), T14(3,4), T14(3,2), T14(1,3), T14(2,1)]';

T15= Tz(l0)*Rz(th1)*Tz(l1)*Rx(th2 )*Ry(th3 ) * Rz(th4 )*Tz(th5 )*Ty(th6 )*Tx(th7 )*Ry(th8)* Tz(l2)* Rx(th9 )*Ry(th10 ) * Rz(th11 )*Tz(th12 )*
J15 = [T15(1,4), T15(2,4), T15(3,4), T15(3,2), T15(1,3), T15(2,1)]';

T16= Tz(l0)*Rz(th1)*Tz(l1)*Rx(th2 )*Ry(th3 ) * Rz(th4 )*Tz(th5 )*Ty(th6 )*Tx(th7 )*Ry(th8)* Tz(l2)* Rx(th9 )*Ry(th10 ) * Rz(th11 )*Tz(th12 )*
J16 = [T16(1,4), T16(2,4), T16(3,4), T16(3,2), T16(1,3), T16(2,1)]';

T17= Tz(l0)*Rz(th1)*Tz(l1)*Rx(th2 )*Ry(th3 ) * Rz(th4 )*Tz(th5 )*Ty(th6 )*Tx(th7 )*Ry(th8)* Tz(l2)* Rx(th9 )*Ry(th10 ) * Rz(th11 )*Tz(th12 )*
J17 = [T17(1,4), T17(2,4), T17(3,4), T17(3,2), T17(1,3), T17(2,1)]';

T18= Tz(l0)*Rz(th1)*Tz(l1)*Rx(th2 )*Ry(th3 ) * Rz(th4 )*Tz(th5 )*Ty(th6 )*Tx(th7 )*Ry(th8)* Tz(l2)* Rx(th9 )*Ry(th10 ) * Rz(th11 )*Tz(th12 )*
J18 = [T18(1,4), T18(2,4), T18(3,4), T18(3,2), T18(1,3), T18(2,1)]';

T19= Tz(l0)*Rz(th1)*Tz(l1)*Rx(th2 )*Ry(th3 ) * Rz(th4 )*Tz(th5 )*Ty(th6 )*Tx(th7 )*Ry(th8)* Tz(l2)* Rx(th9 )*Ry(th10 ) * Rz(th11 )*Tz(th12 )*
J19 = [T19(1,4), T19(2,4), T19(3,4), T19(3,2), T19(1,3), T19(2,1)]';

T20= Tz(l0)*Rz(th1)*Tz(l1)*Rx(th2 )*Ry(th3 ) * Rz(th4 )*Tz(th5 )*Ty(th6 )*Tx(th7 )*Ry(th8)* Tz(l2)* Rx(th9 )*Ry(th10 ) * Rz(th11 )*Tz(th12 )*
J20 = [T20(1,4), T20(2,4), T20(3,4), T20(3,2), T20(1,3), T20(2,1)]';

T21= Tz(l0)*Rz(th1)*Tz(l1)*Rx(th2 )*Ry(th3 ) * Rz(th4 )*Tz(th5 )*Ty(th6 )*Tx(th7 )*Ry(th8)* Tz(l2)* Rx(th9 )*Ry(th10 ) * Rz(th11 )*Tz(th12 )*
J21 = [T21(1,4), T21(2,4), T21(3,4), T21(3,2), T21(1,3), T21(2,1)]';

J = [J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15 J16 J17 J18 J19 J20 J21];
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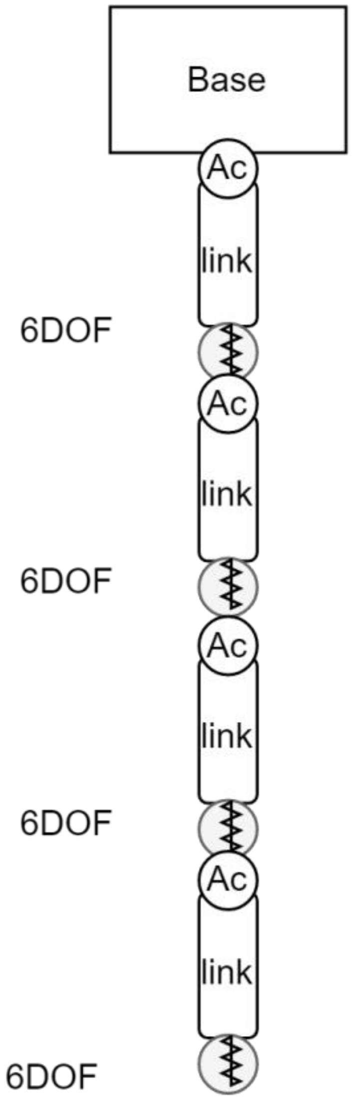
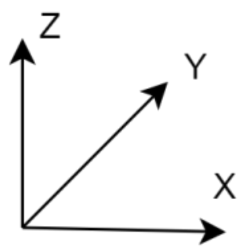
Activate Windows

Fanuc R2000 with Positioner

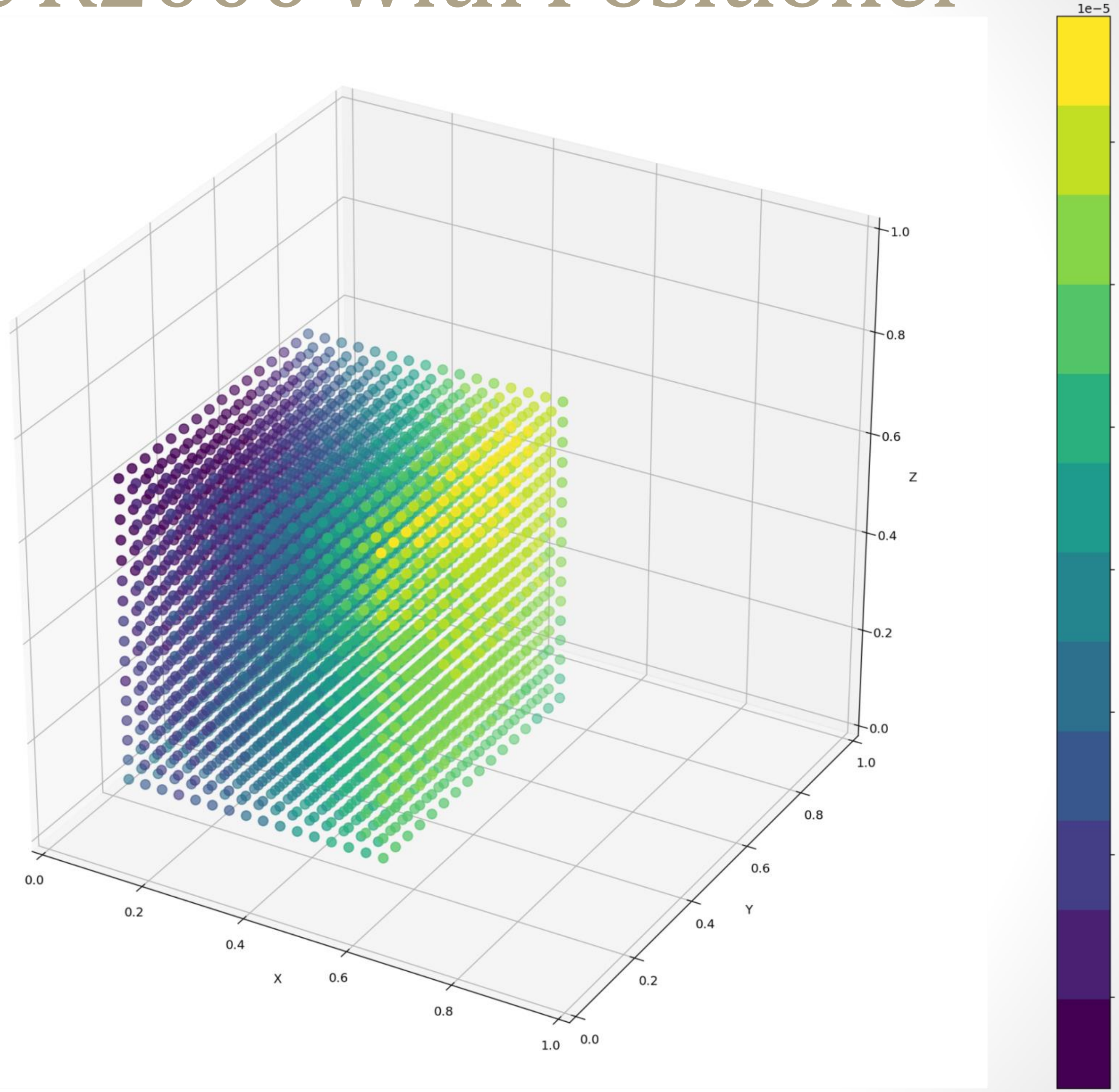
- Why did we do that?

- Results?





Fanuc R2000 with Positioner



- Results?

Fanuc R2000 with Positioner

- Elastostatic Calibration :
- why it's important? Calculate deflections.

$$\mathbf{t} = g(\mathbf{q}, \boldsymbol{\theta}, \boldsymbol{\pi}) \qquad\qquad \boldsymbol{\theta} = \mathbf{k}_\theta \cdot \mathbf{J}_\theta^T \cdot \mathbf{F}$$

where $g(.)$ defines the manipulator *extended geometric model*, $\mathbf{q}$ is the vector of actuated coordinates, $\boldsymbol{\theta}$ is the vector of robot elastostatic deflections, and the vector of the parameters $\boldsymbol{\pi} = \boldsymbol{\pi}_0 + \Delta\boldsymbol{\pi}$ is presented as the sum of the nominal component $\boldsymbol{\pi}_0$ and geometrical errors $\Delta\boldsymbol{\pi}$ to be identified via calibration.

$$\mathbf{t} = \mathbf{g}_0 + \mathbf{J}_\pi \cdot \Delta\boldsymbol{\Pi} + \mathbf{J}_\theta \cdot \mathbf{k}_\theta \cdot \mathbf{J}_\theta^T \cdot \mathbf{F}$$

Fanuc R2000 with Positioner

- Elastostatic Calibration :

$$\sum_{i=1}^{m} \left\| \mathbf{t}_i - \mathbf{g}_{0i} - \mathbf{J}_{\pi i} \cdot \Delta\boldsymbol{\pi} - \mathbf{J}_{\theta \mathrm{i}} \cdot \mathbf{k}_\theta \cdot \mathbf{J}_{\theta \mathrm{i}}^T \cdot \mathbf{F}_i \right\|^2 \to \min_{\Delta\boldsymbol{\pi}, \mathbf{k}_\theta}$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} \left\| \mathbf{p}_{ij} - \mathbf{g}_{0ij}^{(p)} - \mathbf{J}_{\pi ij}^{(p)} \cdot \Delta\boldsymbol{\pi} - \left[\mathbf{J}_{\theta \mathrm{ij}} \cdot \mathbf{k}_\theta \cdot \mathbf{J}_{\theta \mathrm{ij}}^T \cdot \mathbf{F}_i \right]^{(p)} \right\|^2 \to \min_{\Delta\boldsymbol{\pi}, \mathbf{k}_\theta}$$

Then we find the elasticity parameters.

Fanuc R2000 with Positioner

- Geometrical Calibration and Redundancy Resolution :
- https://www.overleaf.com/project/62568740a75a7946f334584a
- Code:
- Redundancy Resolution
- Geometrical Calibration