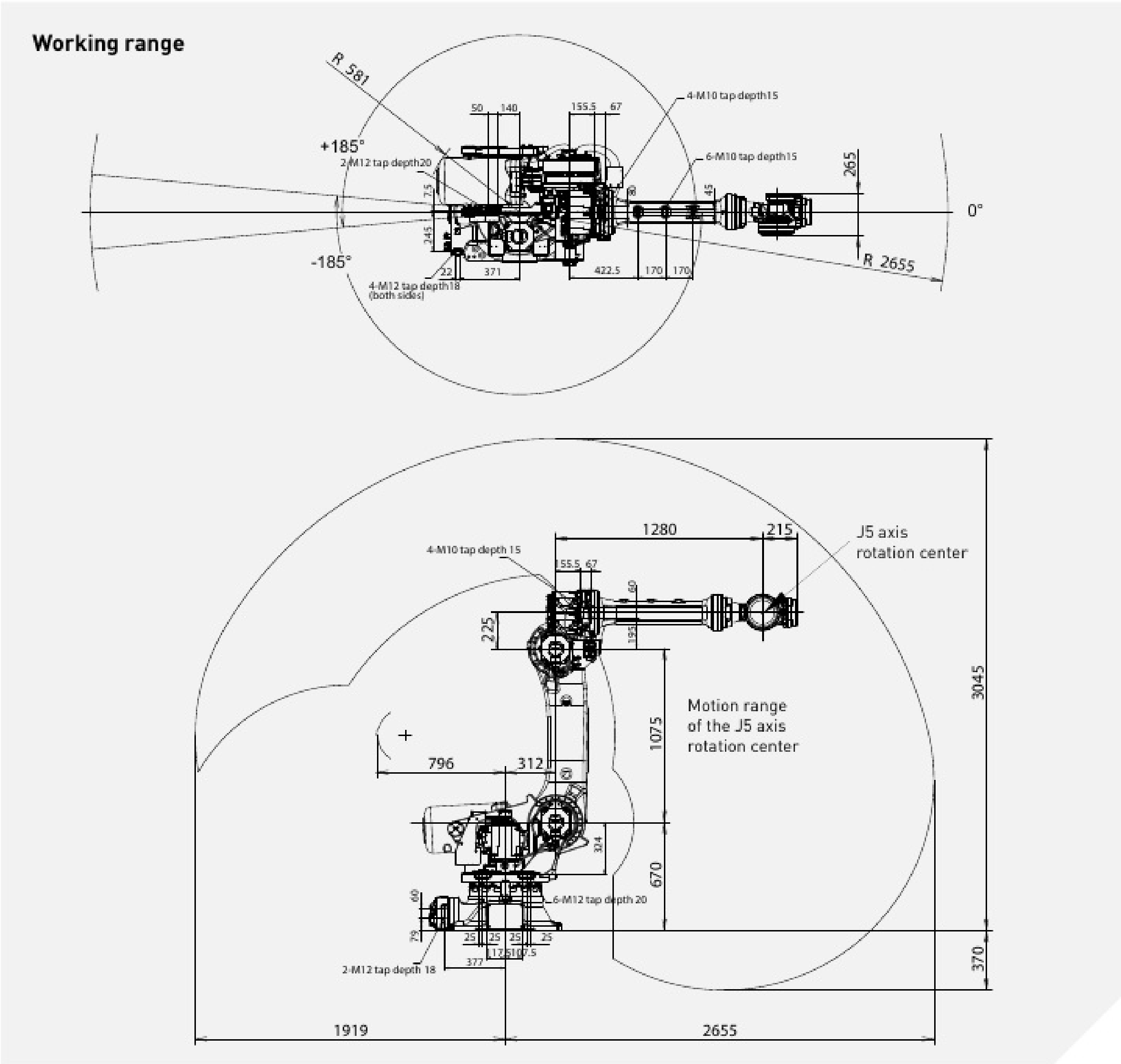
Assignment3

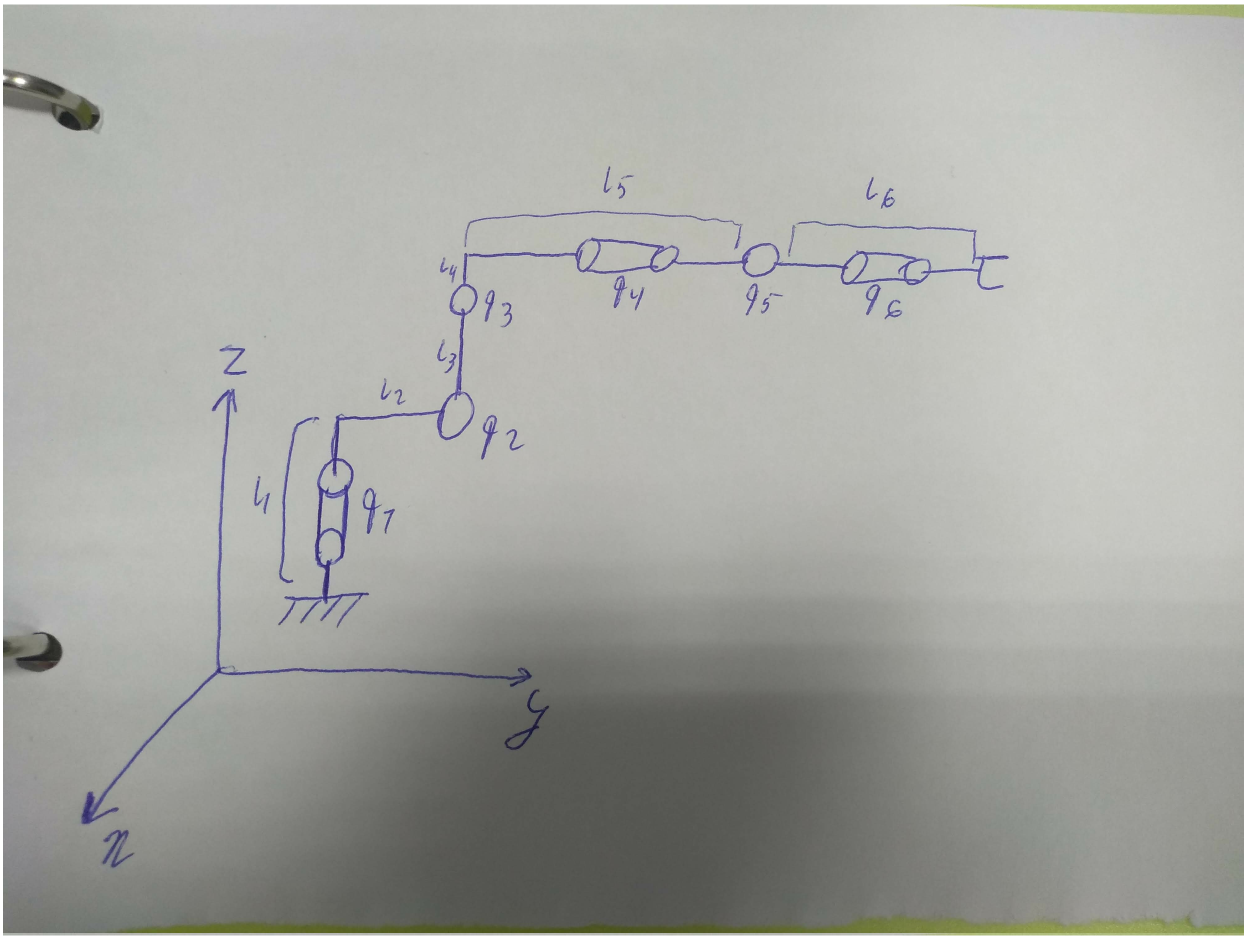
Jacobians computation for FANUC R-2000iC/165F

Robot description

- 6 degree of freedom manipulator with spherical wrist FANUC R-2000iC/165
- Construction weight - 1090kg
- Maximal weight of the load - 165kg
- Maximal reachable distance - 2655mm



Geometrical data about the robot



Kinematic scheme of the robot

Modeling

- Complete model for the robot:

  $T = T_{base}\, T_{z0}\, R_z(q1 + dq1)[T_{x1}\, T_{y1}\, R_{x1}\, R_{y1}]_{L1}\, R_x(q2 + dq2)[T_{z2}\, T_{y2}\, R_{z2}\, R_{y2}]_{L2}\, R_x(q3 + dq3)[T_{z3}\, T_{y3}\, R_{z3}\, R_{y3}]_{L3}\, R_y(q4 + dq4)[T_{z4}\, T_{x4}\, R_{z4}\, R_{x4}]_{L4}\, R_x(q5 + dq5)[T_{z5}\, T_{y5}\, R_{z5}\, R_{y5}]_{L5}\, R_y(q6 + dq6)[T_{z6}\, T_{x6}\, R_{z6}\, R_{x6}]_{L6}\, T_{tool}$

- where q1, q2, q3, q4, q5, q6 - joint angles, dq1, dq2, dq3, dq4, dq5, dq6 - errors in joint angles, T_{z0} - translation of first link (on l1, with error), T_{y1} - translation of 2nd link (on l2, with error), T_{z2} - translation of 3rd link (on l3, with error), T_{z3}, T_{y3} - translations of 4th link (on l4 by z and l5 by y, with error), other matrices stand for errors in links and joints mounts positions

- Move T_{z0} to base, 6th link to tool, apply reduction rules and get the following irreducible model:

  $T = T_{base}\, R_z(q1 + dq1)[T_{x1}\, T_{y1}\, R_{y1}]_{L1}\, R_x(q2 + dq2)[T_{z2}\, R_{z2}\, R_{y2}]_{L2}\, R_x(q3 + dq3)[T_{z3}\, T_{y3}\, R_{z3}]_{L3}\, R_y(q4 + dq4)[T_{z4}\, T_{x4}\, R_{z4}]_{L4}\, R_x(q5 + dq5)[T_{z5}\, R_{z5}]_{L5}\, R_y(q6 + dq6)T_{tool}$

- Calibration procedure:

  i. Initially set all errors to 0
  ii. Generate 30 random configurations
  iii. Compute the expected (calculated from estimated model) tools positions and transformation matrix for robot (for 3 tools) and real (from the model which include real error values)
  iv. From estimated transformation matrix get position and orientation of end effector relative to base, make skew-symmetric matrix for position vector
  v. Estimate base and tools positions by formula (where [~p] - skew symmetric matrix from 4, Δp_i - difference between true and estimated position value for all tools from ith measured configuration, A has dimensions 9x15 since there are 3 tools):

$$\mathbf{A}_i^j = \begin{bmatrix} \mathbf{I} & [\sim \mathbf{p}^i_{robot}]^T & \mathbf{R}^i_{robot} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{I} & [\sim \mathbf{p}^i_{robot}]^T & \mathbf{0} & \mathbf{R}^i_{robot} & \cdots & \mathbf{0} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \mathbf{I} & [\sim \mathbf{p}^i_{robot}]^T & \mathbf{0} & \mathbf{0} & \cdots & \mathbf{R}^i_{robot} \end{bmatrix}$$

$$\left[\mathbf{p}_{base}; \mathbf{r}_{base}; \mathbf{u}^1_{tool}; \ldots \mathbf{u}^n_{tool}\right] = \left(\sum_{i=1}^{m} \mathbf{A}_i^{j^T} \mathbf{A}_i^j\right)^{-1} \left(\sum_{i=1}^{m} \mathbf{A}_i^{j^T} \Delta\mathbf{p}_i\right)$$

  vi. Compute (using numerical method) Jacobians of matrix $T_{base}T_{robot}T_{tool}$ by error parameters
  vii. Compute new parameters for robot transformation matrix by formula (m = 30 - num of experiments, j = 3 - num of tools):

$$\mathbf{\Pi} = \left(\sum_{i=1}^{m}\sum_{j=1}^{n} \mathbf{J}_i^{j(p)^T} \mathbf{J}_i^{j(p)}\right)^{-1} \left(\sum_{i=1}^{m}\sum_{j=1}^{n} \mathbf{J}_i^{j(p)^T} \Delta\mathbf{p}_i^j\right)$$

  viii. Repeat 2 - 7 during some number of iterations