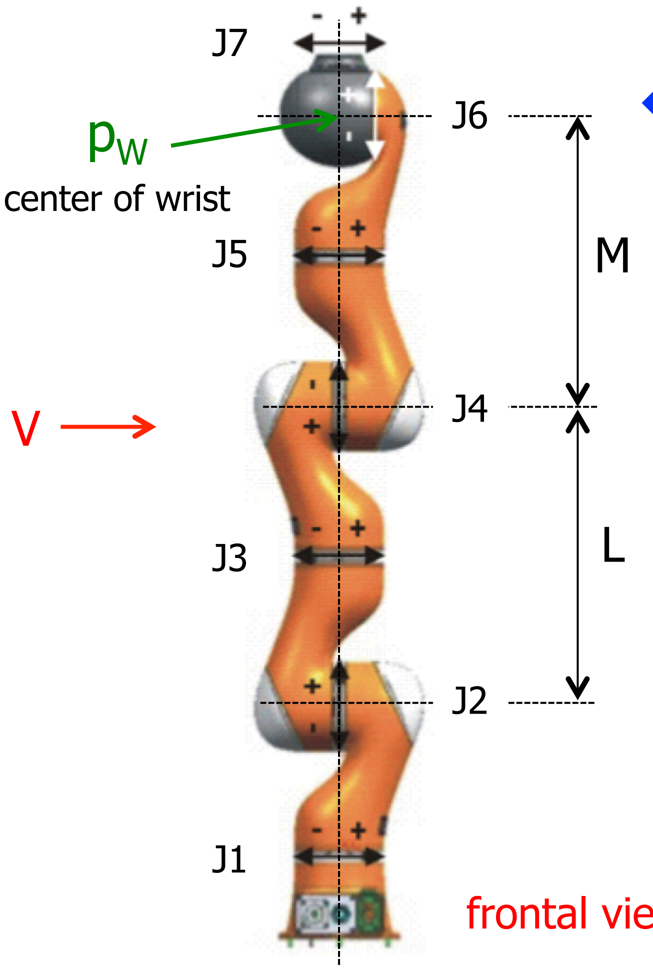
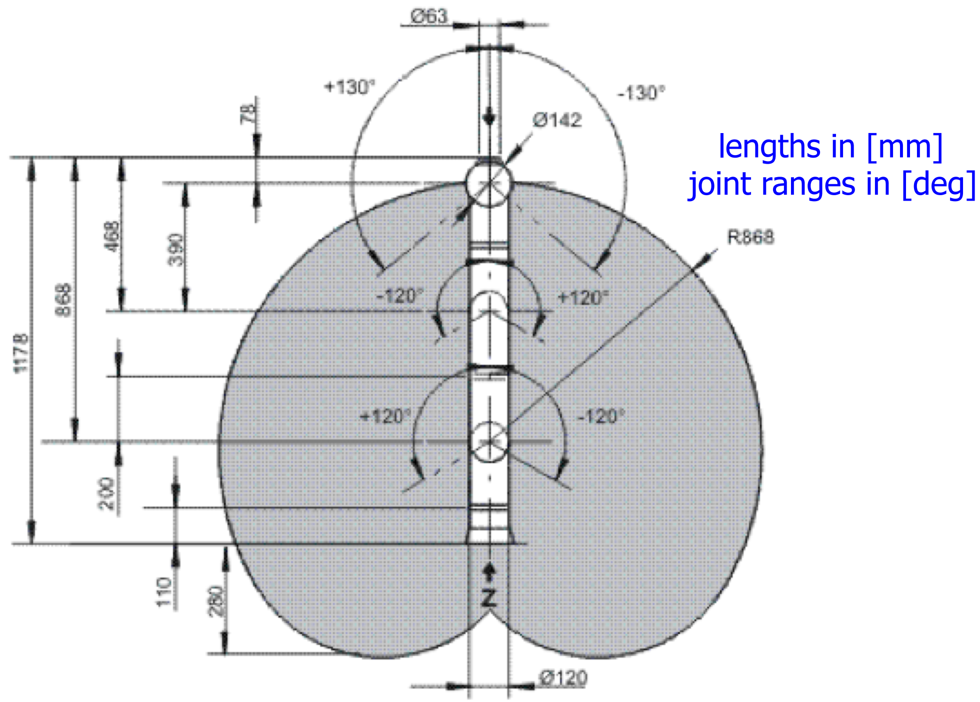
KUKA LWR-IV

- 7R manipulator: spherical shoulder (3R), elbow joint (1R), spherical wrist (3R)



frontal view

- the robot is shown in its zero configuration (**q**=**0**)
- positive directions of joint rotations are indicated

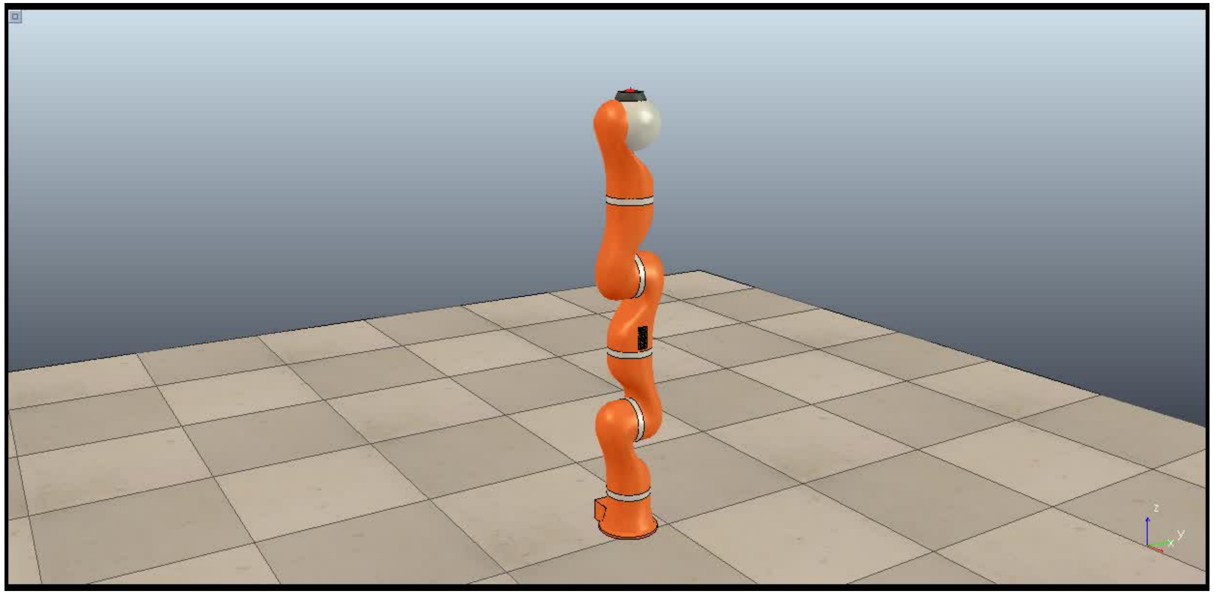


side view (from observer in V)

KUKA LWR-IV in motion

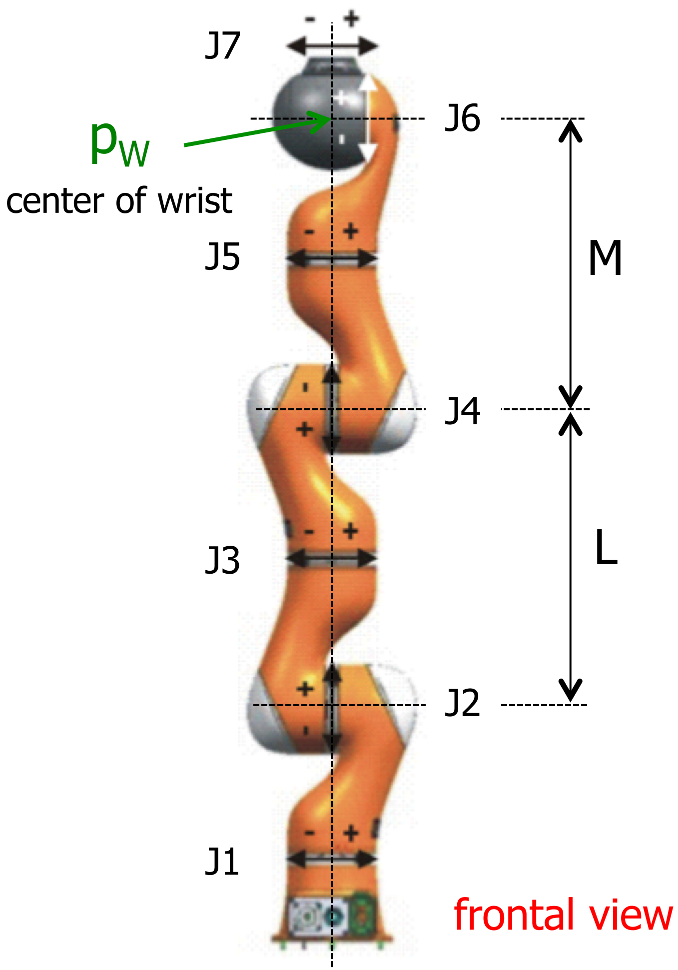
side view from observer in V

videos at DIAG Robotics Lab



VREP video

KUKA LWR-IV



- determine
  - frames and table of D-H parameters
    - be consistent with positive rotations indicated by KUKA
    - only the two kinematic lengths L and M should be needed
  - homogeneous transformation matrices
  - direct kinematics of the center of wrist p_W in symbolic form
  - numerically, in the configuration

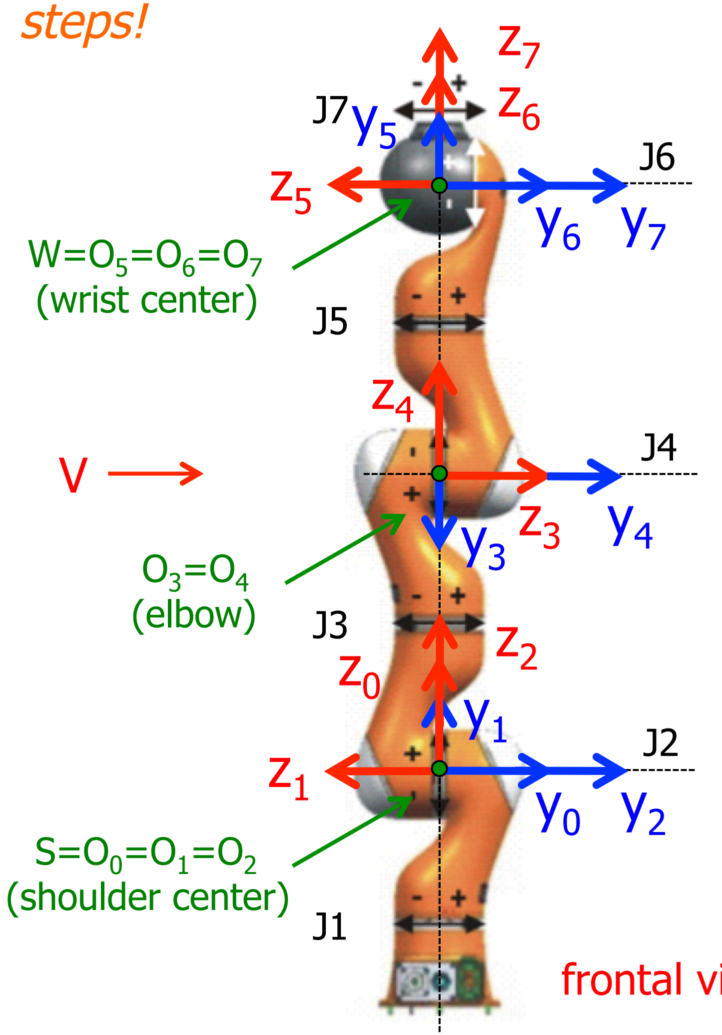
    $$q = (0, \pi/2, \pi/2, -\pi/2, 0, \pi/2, 0) \quad [\text{rad}]$$

    the position ${}^0p_d$ in frame 0 of a tool point P_d whose coordinates in frame 7 are given by

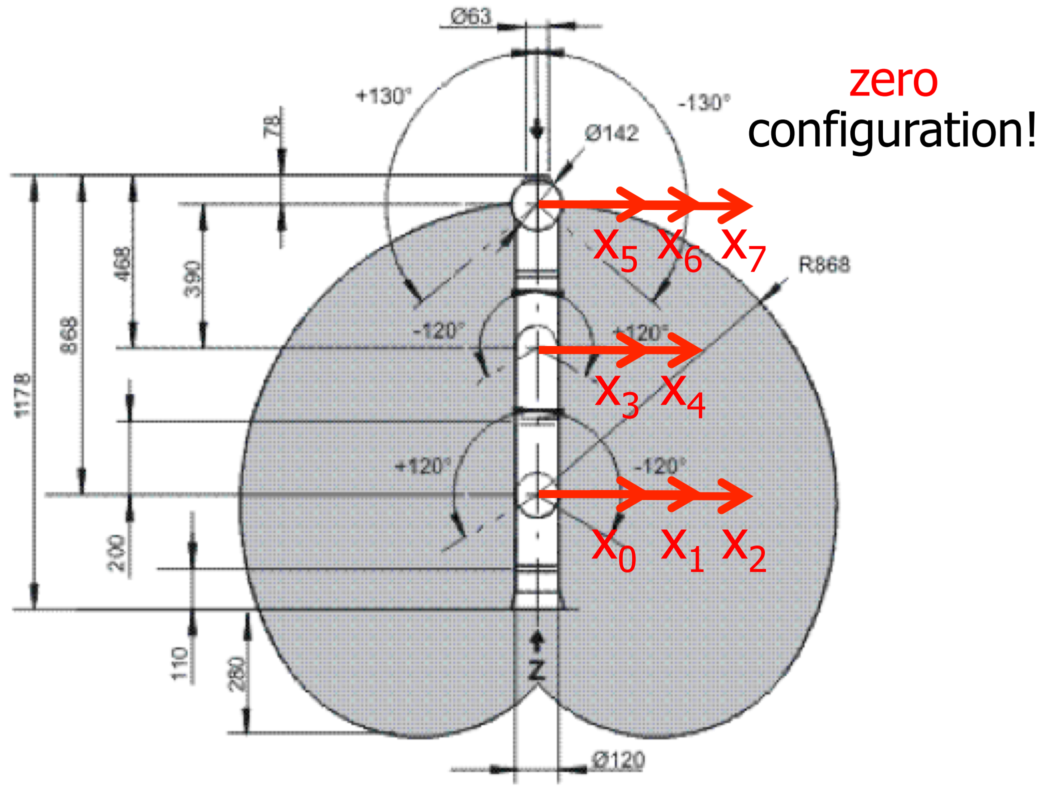
    $${}^7p_d = (0, 0.05, 0.1) \quad [\text{m}]$$

Assignment of D-H frames

steps!

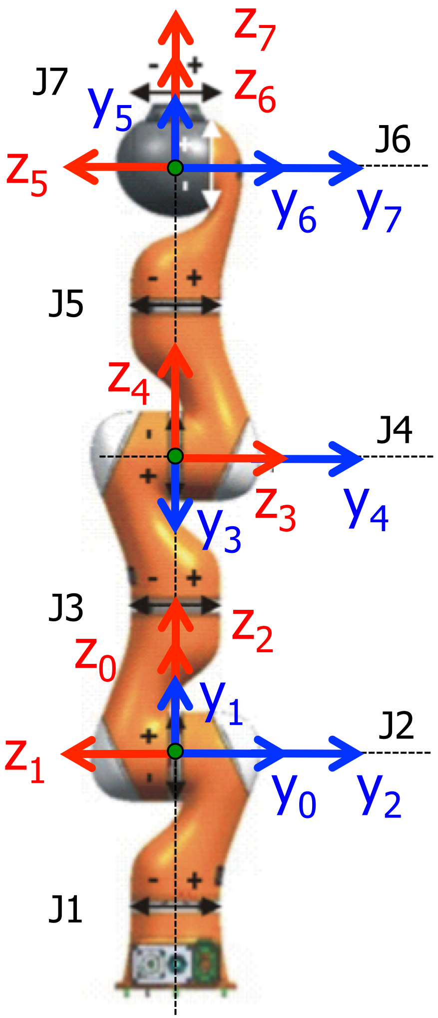


frontal view



side view (from observer in V)

Table of D-H parameters



i	α_i	d_i	a_i	θ_i
1	$\pi/2$	0	0	$q_1=0$
2	$-\pi/2$	0	0	$q_2=0$
3	$-\pi/2$	L	0	$q_3=0$
4	$\pi/2$	0	0	$q_4=0$
5	$\pi/2$	M	0	$q_5=0$
6	$-\pi/2$	0	0	$q_6=0$
7	0	0	0	$q_7=0$

in the shown configuration

with

$$d_3 = L = 0.40, \quad d_5 = M = 0.39 \quad [m]$$

D-H homogeneous matrices

output from Matlab (symbolic) program

```
A1 =

[ cos(q1), 0,  sin(q1), 0]
[ sin(q1), 0, -cos(q1), 0]
[       0, 1,        0, 0]
[       0, 0,        0, 1]


A2 =

[ cos(q2),  0, -sin(q2), 0]
[ sin(q2),  0,  cos(q2), 0]
[       0, -1,        0, 0]
[       0,  0,        0, 1]


A3 =

[ cos(q3),  0, -sin(q3), 0]
[ sin(q3),  0,  cos(q3), 0]
[       0, -1,        0, L]
[       0,  0,        0, 1]


A4 =

[ cos(q4), 0,  sin(q4), 0]
[ sin(q4), 0, -cos(q4), 0]
[       0, 1,        0, 0]
[       0, 0,        0, 1]
```

```
A5 =

[ cos(q5), 0,  sin(q5), 0]
[ sin(q5), 0, -cos(q5), 0]
[       0, 1,        0, M]
[       0, 0,        0, 1]


A6 =

[ cos(q6),  0, -sin(q6), 0]
[ sin(q6),  0,  cos(q6), 0]
[       0, -1,        0, 0]
[       0,  0,        0, 1]


A7 =

[ cos(q7), -sin(q7), 0, 0]
[ sin(q7),  cos(q7), 0, 0]
[       0,        0, 1, 0]
[       0,        0, 0, 1]
```

Direct kinematics of the wrist center

output from Matlab (symbolic) program

$$p_{W,hom} = A_1(q_1)A_2(q_2)A_3(q_3)A_4(q_4)\underbrace{A_5(q_5)A_6(q_6)A_7(q_7)\cdot[0\ 0\ 0\ 1]^T}$$

these can be replaced (by inspection) with $[0\ 0\ M\ 1]^T$

the last three (spherical) joints do not move W

$$= A_1(q_1)A_2(q_2)A_3(q_3)A_4(q_4)\cdot[0\ 0\ M\ 1]^T$$

faster (symbolic) recursive position transformations
(matrix · vector products, in homogenous coordinates)

```
pW =

 - cos(q1)*(sin(q2)*(L + M*cos(q4)) - M*cos(q2)*cos(q3)*sin(q4)) - M*sin(q1)*sin(q3)*sin(q4)
   M*cos(q1)*sin(q3)*sin(q4) - sin(q1)*(sin(q2)*(L + M*cos(q4)) - M*cos(q2)*cos(q3)*sin(q4))
                                                cos(q2)*(L + M*cos(q4)) + M*cos(q3)*sin(q2)*sin(q4)
```

Tool position evaluation

output from Matlab (numerical) program

- in the given configuration $q = (0, \pi/2, \pi/2, -\pi/2, 0, \pi/2, 0)$ [rad] for the tool point P_d of coordinates (in frame 7) ${}^7p_d = (0, 0.05, 0.1)$ [m]

$$ {}^0p_{d,hom} = A_1(q_1)A_2(q_2)A_3(q_3)A_4(q_4)A_5(q_5)A_6(q_6)A_7(q_7)\,{}^7p_{d,hom} $$

etc.

again, (numerical) recursive position transformations (matrix ▪ vector products)

```
Anum{1}=subs(A1,{q1},{0});
Anum{2}=subs(A2,{q2},{pi/2});
Anum{3}=subs(A3,{q3,L},{pi/2,0.4});
Anum{4}=subs(A4,{q4},{-pi/2});
Anum{5}=subs(A5,{q5,M},{0,0.39});
Anum{6}=subs(A6,{q6},{pi/2});
Anum{7}=subs(A7,{q7},{0});

pd = [0 0.05 0.1 1]';

for i=N:-1:1
    pd = Anum{i}*pd;
end

pd=pd(1:3)
```

numerical evaluation of symbolic quantities

${}^7p_d$ in homogeneous coordinates

```
pd =

   -0.3000
   -0.3900
   -0.0500
```