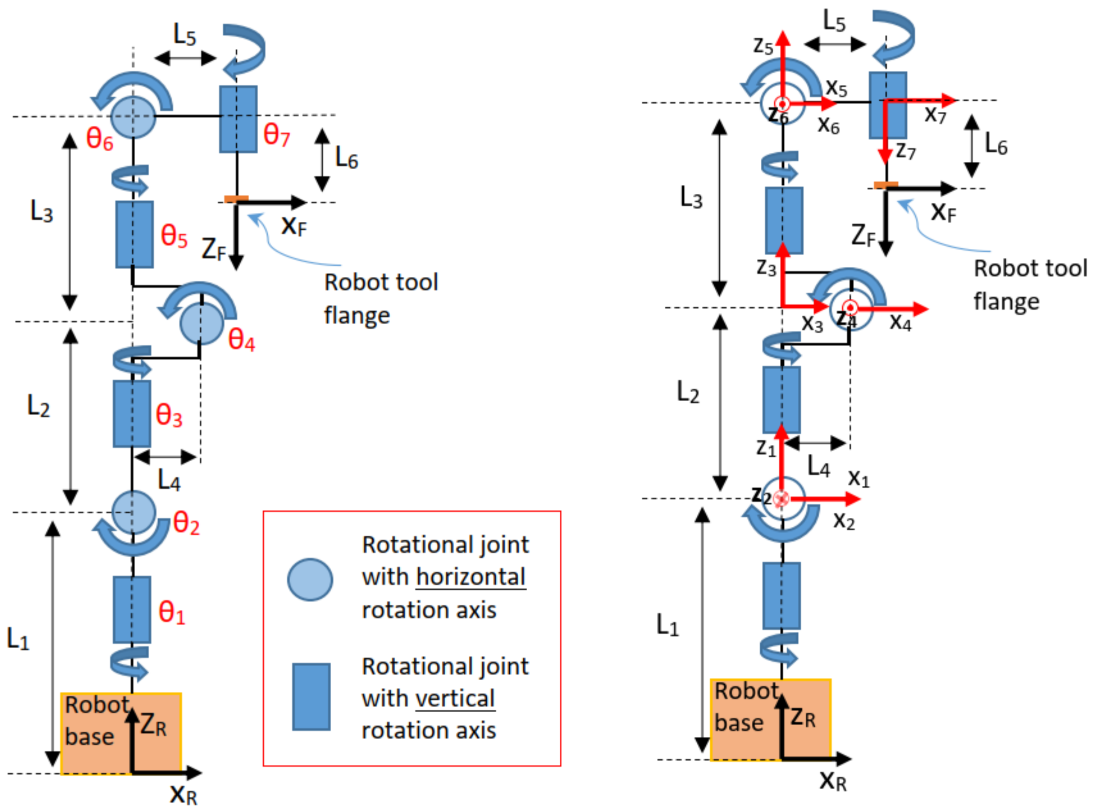
Homework problems 3

The answers to the homework problems should be returned to the corresponding folder on the Robotics-course MyCourses-platform. The answer files should be named as "solutions_homework problems 3_Firstname_Lastname.pdf". Deadline for returning the solutions is Thursday 14.11, 12:00 am, (*before the lectures when the solutions are presented*).

1. In the two figures below the kinematic chain of a seven degree-of-freedom RRRRRRR serial link manipulator mechanism in its home position, i.e. when all the seven rotational joints have a set value zero θ_i=0.0, is shown. The positive directions of rotations are marked with the blue arrow symbols in the figures. Also, some key dimensional lengths, i.e. L_1, L_2, L_3, L_4, L_5, L_6, are



marked in the figures. In the figure to the left, the rotational joint control variables are shown. In the figure to the right, the corresponding link frames are marked. Note that the z-axis of frame 2 is pointing into the paper and the z-axes of frames 4 and 6 out from the paper.

a) <u>The task is to determine the **forward kinematic model** describing the position and orientation of the robot tool flange frame {F} with repect to the robot frame {R}</u>. The positions of the link frames and the directions of the frame axes have already been given (see the figure to the right). Your task is to give the corresponding Denavith-Hartenberg (DH) parameters in a table. Give also the 4x4 homogenous base and tool transformation matrices if required. Use the **Modified** DH-parameters for you forward kinematic model. (*20 points*)

Some background info: The positive directions of rotations determine the direction of the z-axis of each of the link frames according to the right hand rule. In a figure like the one above to the right, It is enough to show only the directions of the axes, which are "parallel to the surface of the paper". The direction of the 3rd axis can always be determined by means of the other two by applying the cross-product rules (eq. 2.12 Corke's book). Note also that when applying the Modified Denavit-Hartenberg parameter convention the z-axes of each of the link frames will be oriented along the physical motor axis of the corresponding degree-of-freedom of the mechanism.

The Modified Denavit-Hartenberg parameter table, initialized with the joint control variables $\boldsymbol{\theta_i}$ and to be updated in regard to the other three DH-parameters $\boldsymbol{\alpha_{i-1}}$, $\boldsymbol{a_{i-1}}$ and $\boldsymbol{d_i}$, is given below:

Link	$\boldsymbol{\alpha_{i-1}}$	$\boldsymbol{a_{i-1}}$	$\boldsymbol{d_i}$	$\boldsymbol{\theta_i}$	$\boldsymbol{\sigma_i}$ (joint type)
1				θ_1	R
2				θ_2	R
3				θ_3	R
4				θ_4	R
5				θ_5	R
6				θ_6	R
7				θ_7	R

b) Create the corresponding simulation model with Corke's robotics toolbox when the numerical values for the L-parameters are as follows:

$L_1 = 0.333$m, $L_2 = 0.316$m , $L_3 = 0.384$m , $L_4 = 0.0825$m , $L_5 = 0.088$m , $L_6 = 0.107$m

For creating the kinematic simulation model you can use the following Matlab toolbox commands:

```
robot1 = SerialLink( [ RevoluteMDH('d',0.333) RevoluteMDH('alpha', value) RevoluteMDH('alpha', value, 'd', value) RevoluteMDH(...) RevoluteMDH(...) RevoluteMDH(...) RevoluteMDH(...)],'name','7axesrob')
```

And for the base and tool transformations (if reguired) use syntax like this:

```
robot1.tool = transl(x_dist, y_dist, z_dist)*trotz(angle, 'deg')
```

After you have created the forward kinematics model for the mechanism with the toolbox, compute the numerical value for the Homogenous 4x4 transformation matrix describing the position and orientation of the tool flange frame {F} with respect to frame {R} attached at the bottom of the robot pedestral in two different robot joint configurations: (*6 points*)

($\theta_1 = 0.0°$, $\theta_2 = -90.0°$, $\theta_3 = 0.0°$, $\theta_4 = 0.0°$, $\theta_5 = 0.0°$, $\theta_6 = 180.0°$, $\theta_7 = 0.0°$)

($\theta_1 = 0.0°$, $\theta_2 = 0.0°$, $\theta_3 = 0.0°$, $\theta_4 = 0.0°$, $\theta_5 = 0.0°$, $\theta_6 = 90.0°$, $\theta_7 = 0.0°$)

Hint: You can assess if your transformation matrices are correct by visually studying at which configuration the robot should be after you "steer" the corresponding joints to orient according to the given joint configurations and then figuring out at which pose the {F} frame should be w.r.t. the {R} frame and does you homogenous transformation matrix you calculated with the Matlab toolbox comply with it.

For calculating the homogenous transformation matrix corresponding to the forward kinematics transform you can use the toolbox command:

```
robot1.fkine([0 0 0 0 0 0 0], 'deg')
```

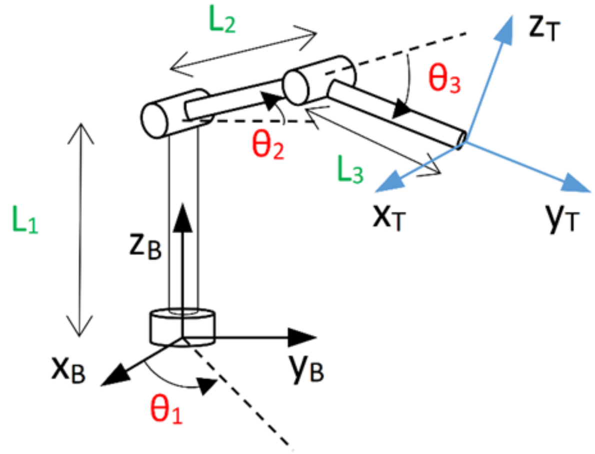
where the numbers within the brackets correspond to corresponding robot joint configuration.

2. In the figure a 3-axes RRR-type manipulator is shown. When all the joint angles have a value zero, the upper arm (i.e. "shoulder" and "elbow" links) is oriented horizontally above the X_B axis. In the joint configuration, shown in the figure, the angle θ_1 has a positive value, the angle θ_2 (angle of the shoulder link with respect to the X_BY_B-plane) has also a positive value but the angle θ_3 which rotates the last link with respect to the "shoulder" link has a negative value.

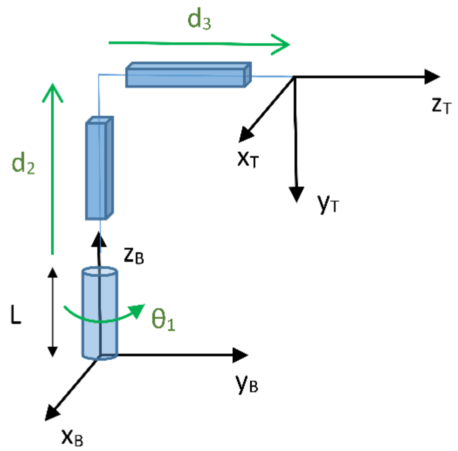
Solve the forward kinematics problem of the manipulator to describe the tool frame {T} with respect to the robot base frame {B}. In other words, assign the link frames in the figure and provide the corresponding DenavitHartenberg-parameters in a table (as well as base and tool transformation matrices).

a) Use the **Standard** Denavit-Hartenberg (DH) parameter convention for your solution. (7 points)

b) Use the **Modified** Denavit-Hartenberg (DH) parameter convention for your solution. (7 points)



3. Find <u>the inverse kinematic transform</u> for the 3-axes RPP-type manipulator, shown in the figure



below. More specifically, find the equations θ_1=f(x,y,z), d_2=f(x,y,z), d_3=f(x,y,z) where (x,y,z) is the position of the origin of the tool frame {T} with respect to the base frame {B} and (θ_1,d_2,d_3) are the joint control variables of the robot. When θ_1=0, the upper arm is oriented above the y_B-axis.
(10 points)