

Robot and interface specifications

Realtime control commands sent to the robot should fulfill *recommended* and *necessary* conditions. Recommended conditions should be fulfilled to ensure optimal operation of the robot. If necessary conditions are not met then the motion will be aborted.

The final robot trajectory is the result of processing the user-specified trajectory ensuring that recommended conditions are fulfilled. As long as necessary conditions are met, the robot will try to follow the user-provided trajectory but it will only match the final trajectory if it also fulfills recommended conditions. If the necessary conditions are violated, an error will abort the motion: if, for instance, the first point of the user defined joint trajectory is very different from robot start position ($q(t = 0) \neq q_c(t = 0)$) a `start_pose_invalid` error will abort the motion.

Values for the constants used in the equations below are shown in the [Limits for Panda](#) and [Limits for Franka Research 3](#) section.

Joint trajectory requirements

Necessary conditions

- $q_{min} < q_c < q_{max}$
- $-\dot{q}_{max} < \dot{q}_c < \dot{q}_{max}$
- $-\ddot{q}_{max} < \ddot{q}_c < \ddot{q}_{max}$
- $-\dddot{q}_{max} < \dddot{q}_c < \dddot{q}_{max}$

Recommended conditions

- $-\tau_{jmax} < \tau_{jd} < \tau_{jmax}$
- $-\dot{\tau}_{jmax} < \dot{\tau}_{jd} < \dot{\tau}_{jmax}$

At the beginning of the trajectory, the following conditions should be fulfilled:

- $q = q_c$
- $\dot{q}_c = 0$
- $\ddot{q}_c = 0$

At the end of the trajectory, the following conditions should be fulfilled:

- $\dot{q}_c = 0$



- $\ddot{q}_c = 0$

Cartesian trajectory requirements

Necessary conditions

- T is proper transformation matrix
- $-\dot{p}_{max} < \dot{p}_c < \dot{p}_{max}$ (Cartesian velocity)
- $-\ddot{p}_{max} < \ddot{p}_c < \ddot{p}_{max}$ (Cartesian acceleration)
- $-\dddot{p}_{max} < \dddot{p}_c < \dddot{p}_{max}$ (Cartesian jerk)

Conditions derived from inverse kinematics:

- $q_{min} < q_c < q_{max}$
- $-\dot{q}_{max} < \dot{q}_c < \dot{q}_{max}$
- $-\ddot{q}_{max} < \ddot{q}_c < \ddot{q}_{max}$

Recommended conditions

Conditions derived from inverse kinematics:

- $-\tau_{jmax} < \tau_{jd} < \tau_{jmax}$
- $-\dot{\tau}_{jmax} < \dot{\tau}_{jd} < \dot{\tau}_{jmax}$

At the beginning of the trajectory, the following conditions should be fulfilled:

- ${}^O T_{EE} = {}^O T_{EEc}$
- $\dot{p}_c = 0$ (Cartesian velocity)
- $\ddot{p}_c = 0$ (Cartesian acceleration)

At the end of the trajectory, the following conditions should be fulfilled:

- $\dot{p}_c = 0$ (Cartesian velocity)
- $\ddot{p}_c = 0$ (Cartesian acceleration)

Controller requirements

Necessary conditions

- $-\dot{\tau}_{jmax} < \dot{\tau}_{jd} < \dot{\tau}_{jmax}$

Recommended conditions

- $-\tau_{jmax} < \tau_{jd} < \tau_{jmax}$



At the beginning of the trajectory, the following conditions should be fulfilled:

- $\tau_{jd} = 0$

Limits for Panda

Limits in the Cartesian space are as follows:

Name	Translation	Rotation	Elbow
\dot{p}_{max}	$1.7 \frac{m}{s}$	$2.5 \frac{rad}{s}$	$2.1750 \frac{rad}{s}$
\ddot{p}_{max}	$13.0 \frac{m}{s^2}$	$25.0 \frac{rad}{s^2}$	$10.0 \frac{rad}{s^2}$
\dddot{p}_{max}	$6500.0 \frac{m}{s^3}$	$12500.0 \frac{rad}{s^3}$	$5000.0 \frac{rad}{s^3}$

Joint space limits are:

Name	Joint 1	Joint 2	Joint 3	Joint 4	Joint 5	Joint 6	Joint 7
q_{max}	2.8973	1.7628	2.8973	-0.0698	2.8973	3.7525	2.8973
q_{min}	-2.8973	-1.7628	-2.8973	-3.0718	-2.8973	-0.0175	-2.8973
\dot{q}_{max}	2.1750	2.1750	2.1750	2.1750	2.6100	2.6100	2.6100
\ddot{q}_{max}	15	7.5	10	12.5	15	20	20
\dddot{q}_{max}	7500	3750	5000	6250	7500	10000	10000
τ_{jmax}	87	87	87	87	12	12	12
$\dot{\tau}_{jmax}$	1000	1000	1000	1000	1000	1000	1000

The arm can reach its maximum extension when joint 4 has angle $q_{elbow-flip}$, where $q_{elbow-flip} = -0.467002423653011 \text{ rad}$. This parameter is used to determine the flip direction of the elbow.

Limits for Franka Research 3

Limits in the Cartesian space are as follows:

Name	Translation	Rotation	Elbow
\dot{p}_{max}	$3.0 \frac{m}{s}$	$2.5 \frac{rad}{s}$	$2.620 \frac{rad}{s}$
\ddot{p}_{max}	$9.0 \frac{m}{s^2}$	$17.0 \frac{rad}{s^2}$	$10.0 \frac{rad}{s^2}$
\dddot{p}_{max}	$4500.0 \frac{m}{s^3}$	$8500.0 \frac{rad}{s^3}$	$5000.0 \frac{rad}{s^3}$



Joint space limits are:

Name	Joint 1	Joint 2	Joint 3	Joint 4	Joint 5	Joint 6	Joint 7
q_{max}	2.7437	1.7837	2.9007	-0.1518	2.8065	4.5169	3.0159
q_{min}	-2.7437	-1.7837	-2.9007	-3.0421	-2.8065	0.5445	-3.0159
\dot{q}_{max}	2.62	2.62	2.62	2.62	5.26	4.18	5.26
\ddot{q}_{max}	10	10	10	10	10	10	10
\ddot{q}_{max}	5000	5000	5000	5000	5000	5000	5000
τ_{jmax}	87	87	87	87	12	12	12
$\dot{\tau}_{jmax}$	1000	1000	1000	1000	1000	1000	1000

The arm can reach its maximum extension when joint 4 has angle $q_{elbow-flip}$, where $q_{elbow-flip} = -0.467002423653011 \text{ rad}$. This parameter is used to determine the flip direction of the elbow.

Important

Note that the maximum joint velocity depends on the joint position. The maximum and minimum joint velocities at a certain joint position are calculated as:

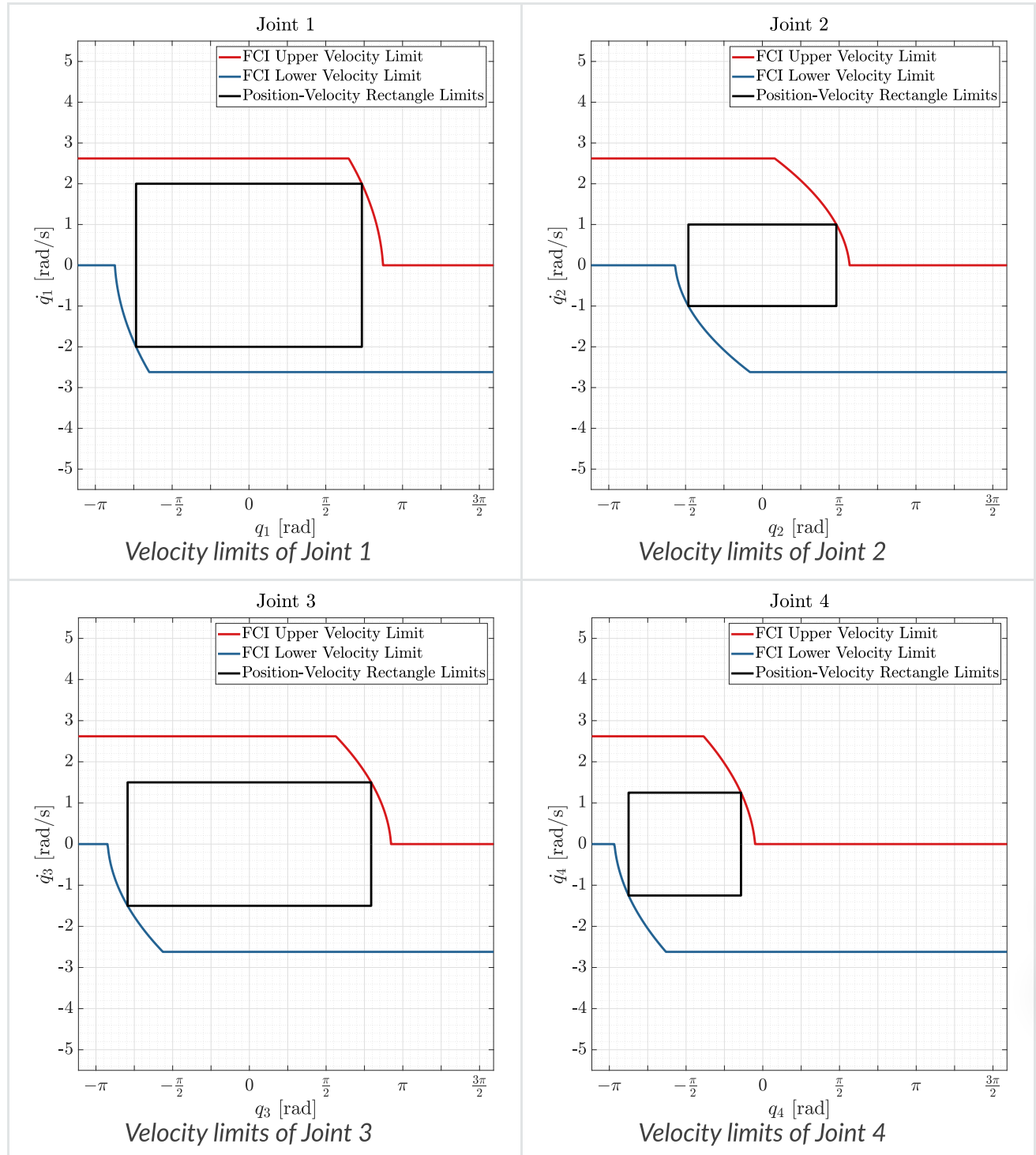
$$\begin{aligned}
 \dot{q}_1(q_1)_{max} &= \min(2.62, \max(0, -0.30 + \sqrt{\max(0, 12.0 * (2.75010 - q_1))})) \\
 \dot{q}_2(q_2)_{max} &= \min(2.62, \max(0, -0.20 + \sqrt{\max(0, 5.17 * (1.79180 - q_2))})) \\
 \dot{q}_3(q_3)_{max} &= \min(2.62, \max(0, -0.20 + \sqrt{\max(0, 7.00 * (2.90650 - q_3))})) \\
 \dot{q}_4(q_4)_{max} &= \min(2.62, \max(0, -0.30 + \sqrt{\max(0, 8.00 * (-0.1458 - q_4))})) \\
 \dot{q}_5(q_5)_{max} &= \min(5.26, \max(0, -0.35 + \sqrt{\max(0, 34.0 * (2.81010 - q_5))})) \\
 \dot{q}_6(q_6)_{max} &= \min(4.18, \max(0, -0.35 + \sqrt{\max(0, 11.0 * (4.52050 - q_6))})) \\
 \dot{q}_7(q_7)_{max} &= \min(5.26, \max(0, -0.35 + \sqrt{\max(0, 34.0 * (3.01960 - q_7))})) \\
 &\text{Maximum velocities} \\
 \dot{q}_1(q_1)_{min} &= \max(-2.62, \min(0, 0.30 - \sqrt{\max(0, 12.0 * (2.750100 + q_1))})) \\
 \dot{q}_2(q_2)_{min} &= \max(-2.62, \min(0, 0.20 - \sqrt{\max(0, 5.17 * (1.791800 + q_2))})) \\
 \dot{q}_3(q_3)_{min} &= \max(-2.62, \min(0, 0.20 - \sqrt{\max(0, 7.00 * (2.906500 + q_3))})) \\
 \dot{q}_4(q_4)_{min} &= \max(-2.62, \min(0, 0.30 - \sqrt{\max(0, 8.00 * (3.048100 + q_4))})) \\
 \dot{q}_5(q_5)_{min} &= \max(-5.26, \min(0, 0.35 - \sqrt{\max(0, 34.0 * (2.810100 + q_5))})) \\
 \dot{q}_6(q_6)_{min} &= \max(-4.18, \min(0, 0.35 - \sqrt{\max(0, 11.0 * (-0.54092 + q_6))})) \\
 \dot{q}_7(q_7)_{min} &= \max(-5.26, \min(0, 0.35 - \sqrt{\max(0, 34.0 * (3.019600 + q_7))})) \\
 &\text{Minimum velocities}
 \end{aligned}$$

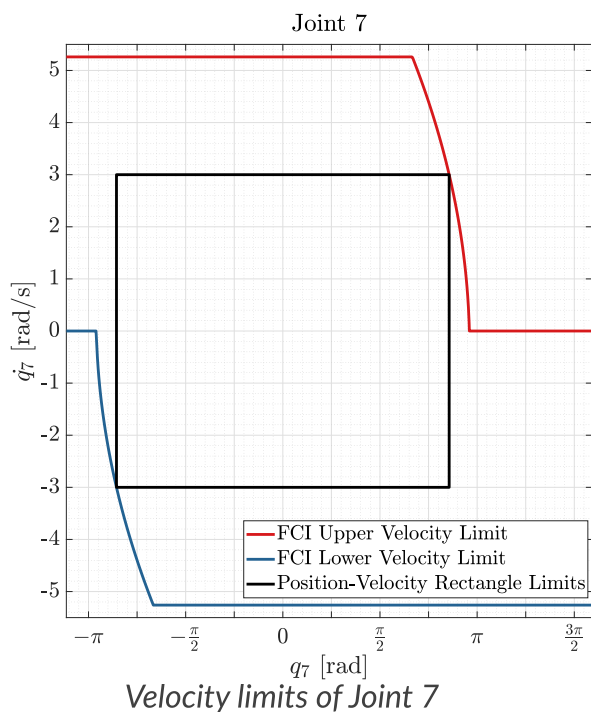
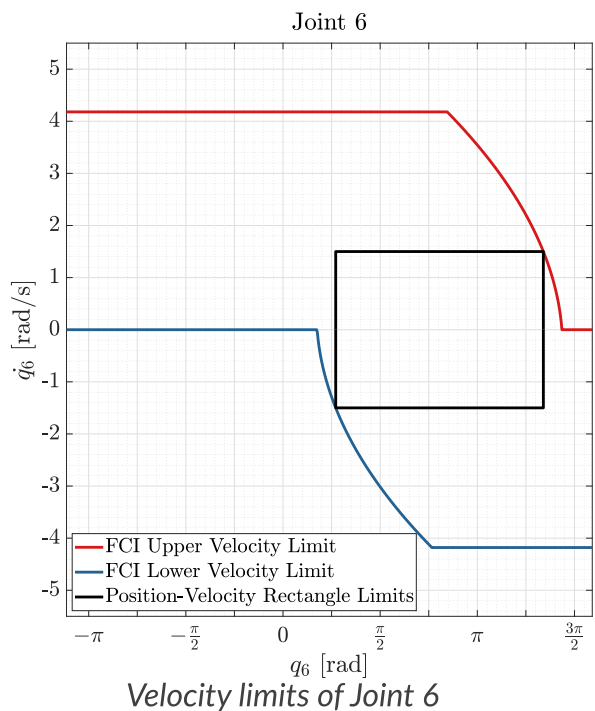
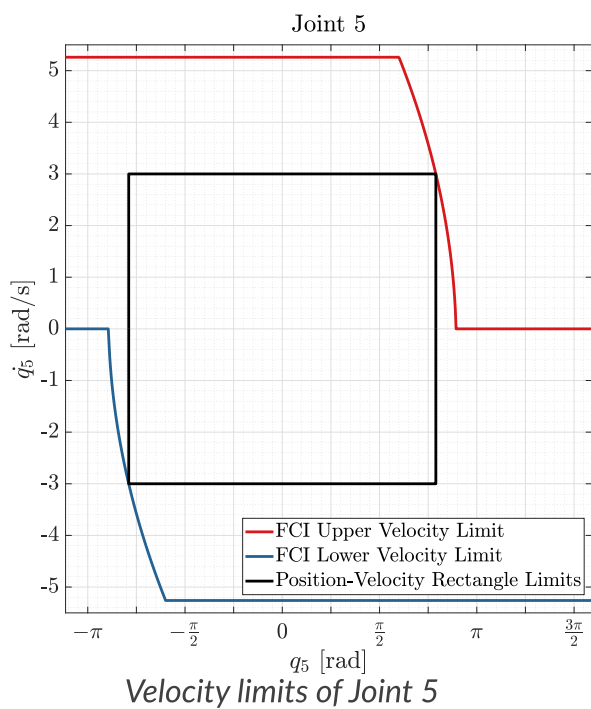
In order to avoid violating the safety joint velocity limits, the Max/Min Joint velocity limits for FCI are more restrictive than those provided in the Datasheet.

As most motion planners cannot deal with those functions for describing the velocity limits of each joint but they only deal with fixed velocity limits (rectangular limits), we are providing here a suggestion on which values to use for them.

In the figures below the system velocity limits are visualized by the red and blue thresholds while the suggested “position-velocity rectangular limits” are visualized in black.

Visualization of the joint limits of FR3





Here are the parameters describing the suggested position-velocity rectangular limits:

Name	Joint 1	Joint 2	Joint 3	Joint 4	Joint 5	Joint 6	Joint 7
q_{max}	2.3093	1.5133	2.4937	-0.4461	2.4800	4.2094	2.6895
q_{min}	-2.3093	-1.5133	-2.4937	-2.7478	-2.4800	0.8521	-2.6895
\dot{q}_{max}	2	1	1.5	1.25	3	1.5	3



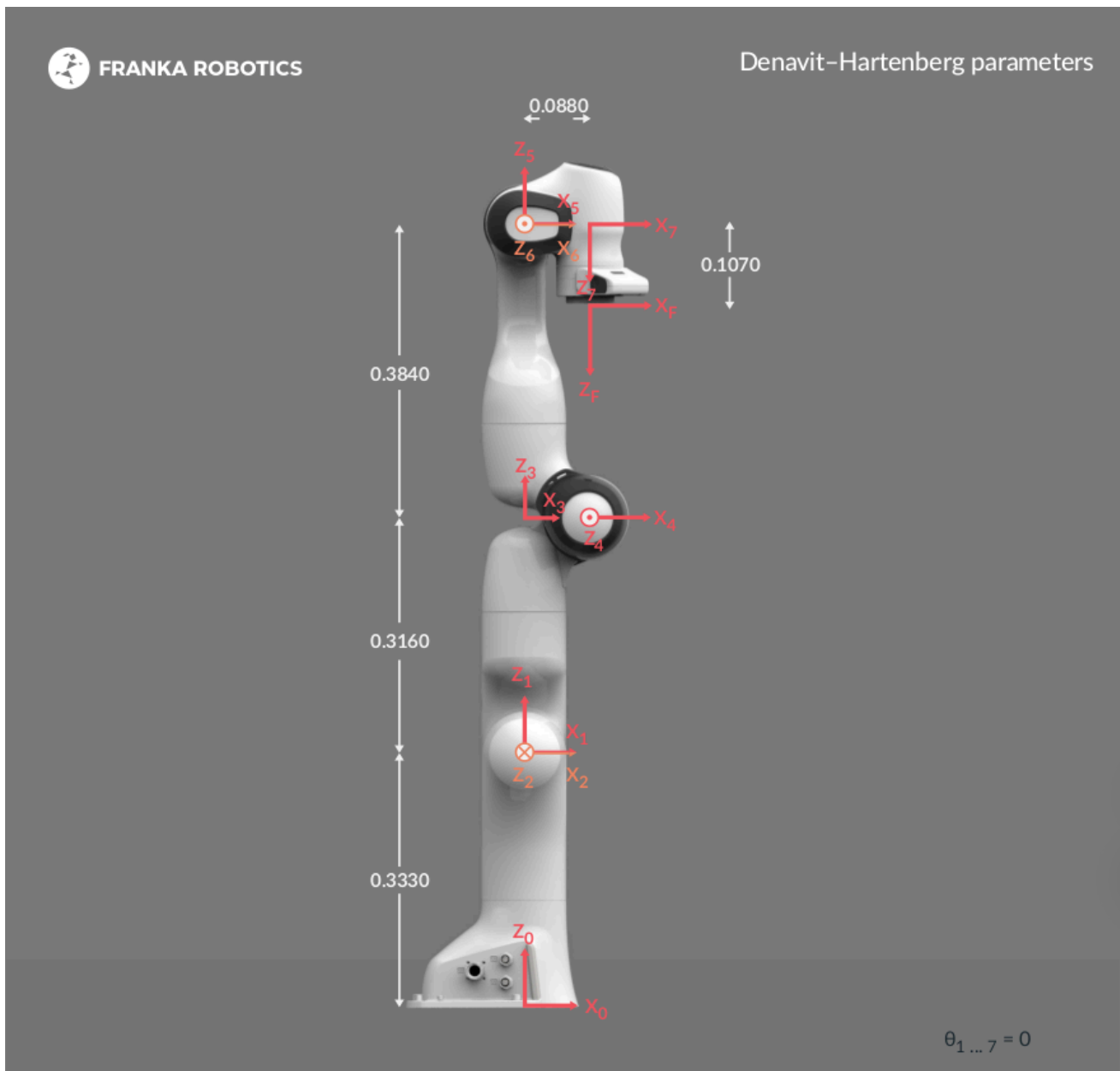
! Important

These limits are the values that are used by default in the rate limiter and in the URDF inside `franka_ros`. However, these are only a suggestion, you are free to define your own rectangles within the specification accordingly to your needs.

Since FR3 does not inherently implement any restriction to the system limits (red and blue line in the plots above), you are also free to implement your own motion generator to exploit the HW capabilities of FR3 beyond the rectangular limits imposed by existing motion generators.

Denavit–Hartenberg parameters

The Denavit–Hartenberg parameters for the Franka Research 3 kinematic chain are derived following Craig’s convention and are as follows:



Franka Research 3 kinematic chain.

Joint	a (m)	d (m)	α (rad)	θ (rad)
Joint 1	0	0.333	0	θ_1

Joint	a (m)	d (m)	α (rad)	θ (rad)
Joint ₂	0	0	$-\frac{\pi}{2}$	θ_2
Joint ₃	0	0.316	$\frac{\pi}{2}$	θ_3
Joint ₄	0.0825	0	$\frac{\pi}{2}$	θ_4
Joint ₅	-0.0825	0.384	$-\frac{\pi}{2}$	θ_5
Joint ₆	0	0	$\frac{\pi}{2}$	θ_6
Joint ₇	0.088	0	$\frac{\pi}{2}$	θ_7
Flange	0	0.107	0	0

! Note

0T_1 is the transformation matrix which describes the position and orientation of *frame 1* in *frame 0*. A kinematic chain can be calculated like the following: ${}^0T_2 = {}^0T_1 * {}^1T_2$

