4.3 Specification of NTU Robot Manipulators

The overall robot manipulators of the experiments used in this thesis are introduced as following, including the parameters of robot kinematics and dynamics. Moreover, the NTU robot arm which is developed by the NTUME Robotic Laboratory is designed for performing dexterous tasks [34, 44].

4.3.1 Six-DOF Robot Manipulator

The six-DOF robot manipulator consists of six active revolution joints and other mechanical components, as shown in Figure 4-5. The joint configurations and standard DH coordinates are shown in Figure 4-6. Based on the definition of kinematic coordinates, we can construct the dynamic parameters of each solid link of the robot as computed by SolidWorks.

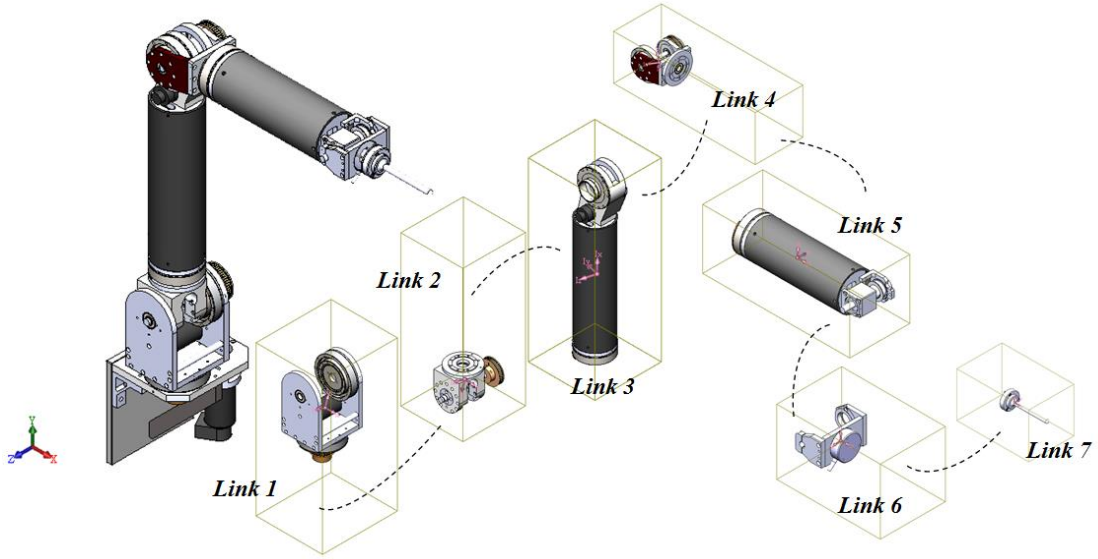

Figure 4-5 The simulation model of 6-axis robot manipulator

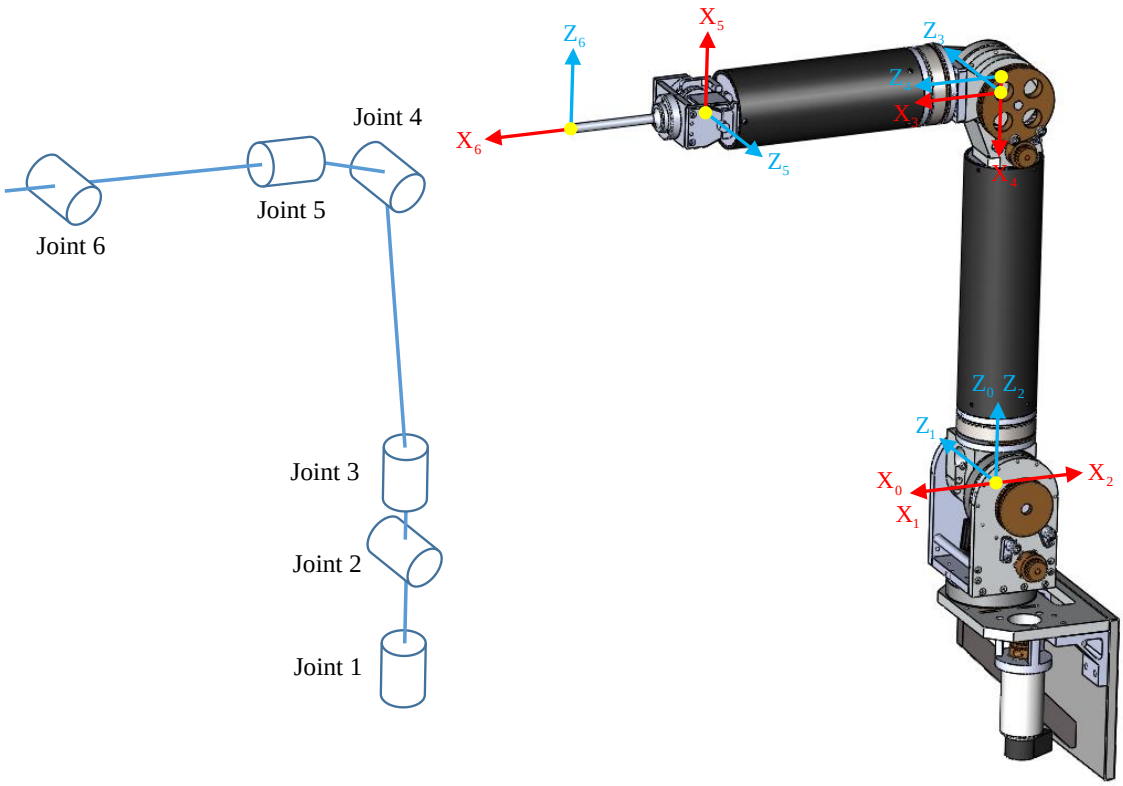

Figure 4-6 The joint configurations and standard DH coordinates

In the following, the parameters of robot kinematics, dynamics, and brushed DC motors are shown in Table 4-1, Table 4-2 and Table 4-3, respectively.

Table 4-1 Kinematic parameters of 6-axis robot manipulator

Joint	**1**	**2**	**3**	**4**	**5**	**6**	**Unit**
DH- a	0	0	10	-10	0	131	*mm*
DH- α	90	90	90	-90	90	90	*deg*
DH- d	0	0	371	0	280	0	*mm*
DH- θ	0	180	180	-90	180	90	*deg*
Joint min	-100	-90	-115	-40	-115	-85	*deg*
Joint max	100	90	115	180	115	85	*deg*
Gear ratio	200	250	200	250	200	300	

Table 4-2 Dynamic parameters of 6-axis robot manipulator (with respect to local frame)

Link		**1**	**2**	**3**	**4**	**5**	**6**	**Unit**
Mass		1.529	0.344	2.034	0.236	1.246	0.274	*kg*
Position of mass center		$\begin{bmatrix}-3.649\\-34.22\\-12.07\end{bmatrix}$	$\begin{bmatrix}0.5776\\6.7729\\19.907\end{bmatrix}$	$\begin{bmatrix}-7.217\\-138.2\\2.4225\end{bmatrix}$	$\begin{bmatrix}3.0856\\-0.338\\34.759\end{bmatrix}$	$\begin{bmatrix}-2.300\\-130.3\\0.4472\end{bmatrix}$	$\begin{bmatrix}0.177\\37.1\\-1.24\end{bmatrix}$	*mm*
Inertia	I_{xx}	35.076	2.987	328.595	3.051	73.442	1.98	$kg \cdot cm^2$
	I_{xy}	0	0	0	0	0	0	$kg \cdot cm^2$
	I_{xz}	0	0	0	0	0	0	$kg \cdot cm^2$
	I_{yy}	21.777	2.606	151.7	1.932	8.267	1.24	$kg \cdot cm^2$
	I_{yz}	0	0	0	0	0	0	$kg \cdot cm^2$
	I_{zz}	24.597	2.629	327.091	2.3	73.509	1.34	$kg \cdot cm^2$

Table 4-3 Motor parameters of 6-axis robot manipulator

Motor	**1**	**2**	**3**	**4**	**5**	**6**	**Unit**
Product	3863-24 CR	3863-24 CR	2642-24 CR	2642-24 CR	2642-24 CR	2232-24 SR	
Nominal voltage	24	24	24	24	24	24	*V*
Max power	214	214	23.2	23.2	23.2	8.68	*W*
Max speed	8000	8000	6000	6000	6000	8000	*rpm*
Max acceleration	121k	121k	120k	120k	120k	120k	rad / s^2
Max torque	157	157	38.06	38.06	38.06	10.593	*mNm*
Torque constant	39.8	39.8	34.6	34.6	34.6	32.1	mNm/A

4.3.2 Eight-DOF Robot Manipulator

The eight-DOF robot manipulator consists of four dual-axis modularized actuator (DAMA) systems, as shown in Figure 4-7. The main concept of a DAMA is that of a vertically intersected dual-axis structure with specific designs to make it modularized. It can serve as a modular two-axis actuator. Hence, a multiple DOF mechanism, such as humanoid robot arms, can be configured in terms of a DAMA.

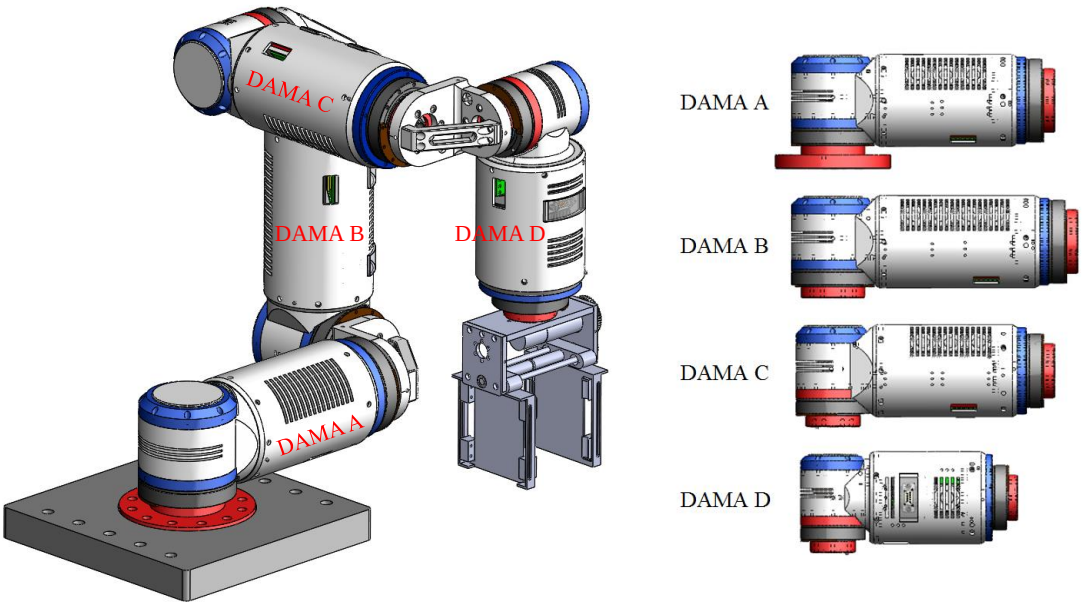

Figure 4-7 The four sets of DAMA are compose the 8-axis robot manipulator

In addition, the 8-axis robot manipulator is a redundant system and has more workspace to let us carry out a greater number of tasks. Figure 4-8 represents the robot joint configurations and standard DH coordinates. Moreover, the parameters of kinematics, dynamics (computed by SolidWorks), and motors are also listed below.

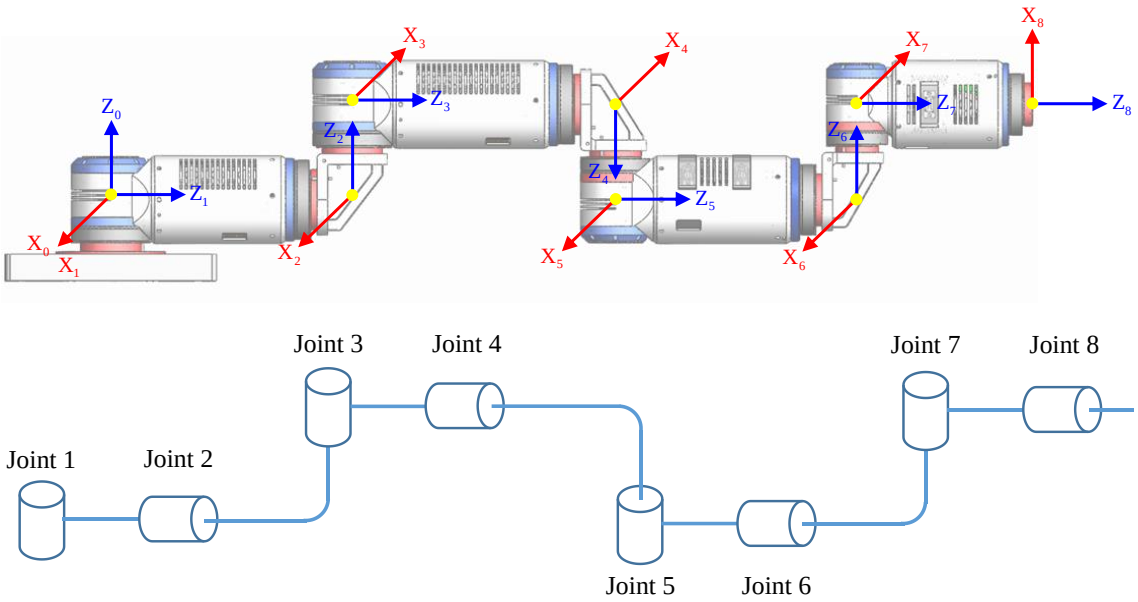

Figure 4-8 The joint configurations and standard DH coordinates

In the following, the parameters of robot kinematics, dynamics, and brushed DC motors are shown in Table 4-4, Table 4-5 and Table 4-6, respectively.

Table 4-4 Kinematic parameters of 8-axis robot manipulator

Joint	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Unit**
DH- a	0	0	0	0	0	0	0	0	*mm*
DH- α	-90	90	90	90	90	90	90	0	*deg*
DH- d	0	275	108	300	108	275	108	200	*mm*
DH- θ	0	0	180	0	180	0	180	90	*deg*
Joint min	-360	-360	-360	-360	-360	-360	-360	-360	*deg*
Joint max	360	360	360	360	360	360	360	360	*deg*
Gear ratio	275	275	275	150	150	100	100	75	

Table 4-5 Dynamic parameters of 8-axis robot manipulator (with respect to local frame)

Link		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Unit**
Mass		3.741	0.476	3.933	0.439	3.446	0.350	2.790	1.194	*kg*
Position of mass center		$\begin{bmatrix} 0.87 \\ 4.15 \\ 99.19 \end{bmatrix}$	$\begin{bmatrix} 0.02 \\ -16.58 \\ 22.27 \end{bmatrix}$	$\begin{bmatrix} -1.01 \\ -4.16 \\ 106.69 \end{bmatrix}$	$\begin{bmatrix} 0.00 \\ -19.36 \\ 21.35 \end{bmatrix}$	$\begin{bmatrix} -0.81 \\ -3.80 \\ 95.17 \end{bmatrix}$	$\begin{bmatrix} 0.00 \\ -20.99 \\ 23.04 \end{bmatrix}$	$\begin{bmatrix} -0.05 \\ -4.05 \\ 80.77 \end{bmatrix}$	$\begin{bmatrix} 7.04 \\ -0.17 \\ -57.7 \end{bmatrix}$	*mm*
Inertia	I_{xx}	74.725	0.570	75.848	0.507	15.523	0.293	6.320	0.004	$kg \cdot cm^2$
	I_{xy}	-0.501	-0.002	-0.345	-0.002	-0.129	0.001	-0.009	0.000	$kg \cdot cm^2$
	I_{xz}	0.760	-0.003	-1.072	-0.002	-0.991	0.001	0.004	0.000	$kg \cdot cm^2$
	I_{yy}	73.136	0.378	74.241	0.359	15.193	0.227	6.017	0.004	$kg \cdot cm^2$
	I_{yz}	4.090	0.227	-3.749	0.196	1.148	0.117	0.451	0.000	$kg \cdot cm^2$
	I_{zz}	10.464	0.324	7.940	0.253	2.112	0.103	1.226	0.007	$kg \cdot cm^2$

Table 4-6 Motor parameters of 8-axis robot manipulator

Motor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Unit**
Product	3863 -24CR	3863 -24 CR	3863 -24 CR	3863 -24 CR	3863 -24CR	3257 -24CR	3257 -24CR	3242 -24CR	
Nominal voltage	24	24	24	24	24	24	24	24	*V*
Max power	214	214	214	214	214	83.2	83.2	26.3	*W*
Max speed	8000	8000	8000	8000	8000	5000	5000	5000	*rpm*
Max acceleration	121k	121k	121k	121k	121k	130k	130k	74k	rad / s^2
Max torque	157	157	157	157	157	70	70	35	*mNm*
Torque constant	39.8	39.8	39.8	39.8	39.8	37.7	37.7	41.3	mNm/A