

Methodology for Integrated Design Optimization of Actuation Systems for Exoskeletons - Supplementary Material

Table S 1: Body Numbering Human Body Model

Number	Name
1	HIPS
2	SPINE
3	CHEST
4	NECK
5	HEAD
6	SHOULDER_R
7	ARM_R
8	FOREARM_R
9	HAND_R
10	SHOULDER_L
11	ARM_L
12	FOREARM_L
13	HAND_L
14	UPLEG_R
15	LEG_R
16	FOOT_R
17	UPLEG_L
18	LEG_L
19	FOOT_L

Table S 2: Body Numbering Exoskeleton Model

Number	Name
1	HIP_BELT
2	BACK_RAIL
3	RIGHT_SWIVEL_JOINT
4	RIGHT_LEG_RAIL
5	LEFT_SWIVEL_JOINT
6	LEFT_LEG_RAIL

Table S 3: Actuator Data

Name	Value
Viscous gear friction $k_{v,gear}$	0 Ns/m
Viscous various friction $k_{v,various}$	0 Ns/m
Static friction k_s	2.5 N
Conversion factor p	261.8

Table S 4: External Load Coupling

Number i	${}^{\text{hum},i}\mathbf{p}_{\text{load},i}$
9	$[0.05 \quad -0.05 \quad 0]^T$
13	$[-0.05 \quad -0.05 \quad 0]^T$

Table S 5: Human Exoskeleton Coupling

Number m	$b_{C,\text{hum}}(m)$	$b_{C,\text{exo}}(m)$	$\mathbf{T}_{C,\text{hum},m}^{\text{hum},b_{C,\text{hum}}(m)}$	$\mathbf{T}_{C,\text{exo},m}^{\text{exo},b_{C,\text{exo}}(m)}$	W_m
1	1	1	$\begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0.02 \\ 0 & 0 & -1 & 0.04 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\{1,2,3,4,5,6\}$
2	3	2	$\begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0.99939 & 0.03489 & 0 \\ 0 & 0.03489 & -0.99939 & -0.11 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0.42 \\ 0 & 0 & 1 & -0.01 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\{1,3\}$
3	14	4	$\begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & -0.075 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 & 0 & -0.1 \\ 0 & 1 & 0 & -0.25 \\ 0 & 0 & 1 & 0.08 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\{1,3\}$
4	17	6	$\begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & -0.075 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 & 0 & 0.1 \\ 0 & 1 & 0 & -0.25 \\ 0 & 0 & 1 & 0.08 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\{1,3\}$

Table S 6: Cable Routing

Number j	Number n	$b_{sec}(j, n)$	${}^{exo, b_{sec}(j, n)}\mathbf{p}_{j, n}$
1	1	2	$[0.1372 \ 0.06 \ -0.0176]^T$
1	2	1	$[0.1391 \ 0.03 \ 0.1055]^T$
1	3	1	$[-0.1192 \ -0.03 \ 0.1053]^T$
1	4	1	$[-0.1168 \ -0.14 \ 0.0932]^T$
1	5	6	$[0.11 \ -0.2 \ 0.09]^T$
2	1	2	$[-0.107 \ 0.06 \ -0.018]^T$
2	2	1	$[-0.109 \ 0.03 \ -0.1216]^T$
2	3	1	$[-0.1192 \ -0.03 \ 0.1053]^T$
2	4	1	$[-0.1168 \ -0.14 \ 0.0932]^T$
2	5	6	$[0.11 \ -0.2 \ 0.09]^T$
3	1	2	$[-0.032 \ 0.06 \ 0.0206]^T$
3	2	1	$[-0.0308 \ 0.03 \ 0.145]^T$
3	3	1	$[-0.1192 \ -0.03 \ 0.1053]^T$
3	4	1	$[-0.1168 \ -0.14 \ 0.0932]^T$
3	5	6	$[0.11 \ -0.2 \ 0.09]^T$
4..6	mirrored on y-z-planes		

Table S 7: Exoskeleton Actuator Coupling

Number j	$b_{act}(j)$	$\mathbf{T}_{C, act, j}^{exo, b_{act}(j)}$			
1	2	-0.06183	0.998079	-0.00383	0.1372
		0.99616	0.06195	0.06174	0.06
		0.06186	0	-0.99808	-0.017587
		0	0	0	1
2	2	0.0658536	0.99782	0.00364756	-0.10699
		0.996295	-0.065954	0.0551838	0.06
		0.055304	0	-0.9984695	-0.001782
		0	0	0	1
3	2	-0.040624	0.99917	-0.0008814	-0.032021
		0.998939	0.040634	0.0216736	0.060
		0.021691	0	-0.99976	0.020618
		0	0	0	1
4..6	mirrored on y-z-plane				

Exoskeleton and Human Mechanical Parameters

Mechanical models for human and exoskeleton are provided as *.osim files. These files contain mechanical parameters.